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THESIS

USING MOTION CAPTURE TO DETERMINE MARKSMANSHIP SHOOTING PROFILES: TEACHING SOLDIERS TO SHOOT BETTER FASTER

by

William "Bill" L. Platte

Johnny J. Powers

September 2008

Thesis Advisor: Anthony Ciavarelli
Second Reader: Joseph Sullivan

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How can the U.S. Army teach soldiers marksmanship skills faster and sustain those skills between live fire training periods? Virtual marksmanship trainers are currently used to provide the means to teach basic and advanced marksmanship skills, monitor performance progress from novice to expert, and maintain marksmanship skills. Our research was focused on the use of virtual marksmanship trainers to explore various training method enhancements based on recent studies of complex skill acquisition and expertise. The study of marksmanship skill and shooting characteristics benefited from the emergence of highly precise instrumentation for digital recording of the subject's performance. We used motion capture technology to define and to measure rifle shooting postural profiles associated with different levels of marksmanship expertise. Motion capture data revealed significant ($p<.008$) differences between beginner and expert profiles. Using this knowledge to develop a training system for the standardization of expert level marksmanship performance would result in higher levels of expertise and the reduction of variance during the instruction of rifle marksmanship.

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William "Bill" L. Platte
Major, United States Army
B.S., North Georgia College, 1996
M.E., Troy State University, 2004

Johnny J. Powers
Major, United States Army
B.A., University of Arkansas at Little Rock, 1993

Submitted in partial fulfillment of the
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September 2008

Authors: William L. Platte
Johnny J. Powers

Approved by: Anthony Ciavarelli
Thesis Advisor

Joseph Sullivan
Second Reader; Director, MOVES

Mathias Kölsch
Chair, MOVES Academic Committee

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ABSTRACT

How can the U.S. Army teach soldiers marksmanship skills faster and sustain those skills between live fire training periods? Virtual marksmanship trainers are currently used to provide the means to teach basic and advanced marksmanship skills, monitor performance progress from novice to expert, and maintain marksmanship skills. Our research was focused on the use of virtual marksmanship trainers to explore various training method enhancements based on recent studies of complex skill acquisition and expertise. The study of marksmanship skill and shooting characteristics benefited from the emergence of highly precise instrumentation for digital recording of the subject's performance. We used motion capture technology to define and to measure rifle shooting postural profiles associated with different levels of marksmanship expertise. Motion capture data revealed significant ($p<.008$) differences between beginner and expert profiles. Using this knowledge to develop a training system for the standardization of expert level marksmanship performance would result in higher levels of expertise and the reduction of variance during the instruction of rifle marksmanship.

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inside of her than anyone I know….let it out and remember that you are a unique individual who is loved. Jacquelynn, you are so smart and funny that it scares me sometimes. You make friends easily and your ability to adapt to new situation is astonishing. Noah, you have more love and energy than I thought possible in a little man your size. I cannot wait to see what kind of young man you become. To all my children, you teach and show me everyday what a lucky man I really am. I love you all.

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I. INTRODUCTION

> Marksmanship training has been one of the fundamental competencies of successful military organizations since projectile weapons replaced edged weapons as the primary tools of the infantry (Yates, 2004).

To truly understand the necessity of marksmanship to the warfighter one must have an appreciation of the history of marksmanship and the current use of simulations to support training.

> The rifle and its accurate use came to the forefront during our own American Revolution. Major General Charles Lee, George Washington's right hand man, had this to say: The frontier riflemen will make fine soldiers (because of above all, the dexterity to which they have arrived in the use of the rifle gun. There is not one of these men who wish a distance less than 200 yards or greater object than an orange. Every shot is fatal. (Bawb, 2008)

The United States Army and the other services have placed a great emphasis on the service member's ability to employ their individual weapon. Current operations have shown that no longer is it just the infantry soldier who has the responsibility "To defeat the enemy though Close Combat" (British Army, 2005).

The ability of a soldier to hit the enemy first is not simply a matter of better marksmanship; it is a matter of life and death on the battlefield. As stated by General Methuen of the British Command during World War I, "Good shooting, accurate judging distance, and intelligent use of ground…" (Bawb, 2008) are fundamental to any infantryman. Leaders of the military must understand the history of warfare and marksmanship to make viable changes to an already proven methodology of marksmanship instruction.

A. PROBLEM STATEMENT

How can the U.S. Army teach soldiers marksmanship skills faster and sustain those skills over time? Our nation is currently involved in a period sustained combat; therefore the military has grown increasingly reliant on the use of simulations to conduct training in preparation for deployment to an operational theater. This has placed an

amplified need for soldiers to report to their unit with more than a simple understanding of basic rifle marksmanship. Instead the soldier now must be prepared to enter combat upon completion of their initial entry and advanced individual training. This requires advanced marksmanship skills that can only be perfected during training. Additionally, ensuring that soldiers are in a constant state of readiness using their individual weapon will allow commanders to focus on collective training sooner in the training cycle.

To what avail is a Drill Sergeant yelling for days on the range if the Soldier has no idea on how to improve their marksmanship abilities? Currently the Drill Sergeant must rely on actually observing the trainee firing their weapon or use the objective data provided by the zero or qualification process. The objective of this research is to provide a means for the Drill Sergeant or marksmanship instructor to enhance their ability to provide useful feedback. Visual feedback could be imperative to the success of the soldier and facilitate a more productive Drill Sergeant. All drill sergeants have good training techniques and procedures, but are by no means streamlined or free of personal bias. If one could create a virtual computer model that could demonstrate the standard of the proper body posture while firing it would alleviate inconsistencies in marksmanship training. From the moment the Soldier arrives at basic training he could immediately visualize what the proper body posture looks like and model himself after Santos virtual posture.

It is essential for every baseball pitcher to visualize throwing a pitch in baseball and hitting the catcher’s mitt. An inability to perform this task makes it very difficult to throw a strike consistently. The same concept applies to the golfer who is trying to hit the ball close to the pin, if the golfer cannot visualize the ball hitting the green; the likelihood of hitting the mark is greatly reduced.

Dr. Richard Coop, a mental instructor to countless PGA Tour professionals, including Ben Crenshaw, Mark O'Meara, and Nick Faldo states:

> Here we find a shot that’s found on a lot of golf courses. It requires an uphill carry to a flag that’s in the back of the green. It’s been my experience that most amateurs and even good players tend to leave this shot considerably short of what they would like to. One of the ways that we can get around this is by using our visualization abilities. I found it

> very helpful to ask players to visualize the flagstick as being the back of a basketball goal, the top of the backboard if you will. Flagsticks are about eight or nine feet on most golf courses except in the British Isles where they are much shorter. I would like for you to visualize the flagstick being at least as high as the back of a basketball goal. Your shots would come up and reach at least that height and then come straight down into the flagstick. If this doesn't work you might even visualize a flagstick as high as a grain elevator or a silo, for those of us who have lived in the mid-west. Make the shot start at the top or the apex of the grain elevator and let it fall right into the flagstick. Now using your visualization skills you'll be able to help the ball get up to the flagstick. As you get behind the ball, visualize the flagstick as being much higher than it is and allow the ball come right down the flagstick. By visualizing the ball coming down the top of the grain elevator or a silo you will get many more of your shots up to the hole. You'll have a lot more birdie shots and you'll be a happier golfer. (Coop, 1996-2008)

B. MOTIVATION

> The use of simulation is ever increasing as U.S. Army capabilities of producing high-fidelity virtual environments increase. This is true for marksmanship and engagement shooting trainers as well (Scribner, Wiley, & Harper, 2007).

During initial entry training soldiers are introduced to military basic rifle marksmanship. This is considered one of the most fundamental of all soldier skills and the minimum standard of shooting 23 out of 40 pop-up targets is necessary to move forward in the training cycle and graduate from basic training (FM 3-22.9 Rifle Marksmanship, 2008). The authors propose the following question, "If the soldier is required to hit only 23 out of 40…what happens to the 17 targets that are not engaged in combat?"

The genesis for this research originated from a combined total of 32 years of military training between the authors'. Army Marksmanship manual FM 3-22.9 (FM 3-22.9 Rifle Marksmanship, 2008) clearly defines the standard a soldier must reach to be an expert marksman. The questions remains, "How does the military teach marksmanship consistently and achieve the results desired to send a soldier into combat immediately upon leaving basic and advanced individual training?" Is the military consistent in how it teaches marksmanship? The characteristics of good rifle marksmanship are common

among the U.S. Army and the Marine Corps with each stating the necessity to become an expert marksman. The U.S. Army defines expert marksmanship as hitting 36 or more targets out of 40 on a pop-up range. (FM 3-22.9 Rifle Marksmanship, 2008) (Marine Corps, 2001) What qualities and posture do expert marksmen possess and are they consistent? If these qualities are clearly identifiable why has there not been an effort to record and visually display with "right" looks like? Better to see "right" the first time than to leave a trainee guessing if the task was performed correctly when the Drill Sergeant is not present to issue corrective instruction. This knowledge of what correct looks like also facilitates peer instruction because now the soldier's battle buddy can provide knowledgeable feedback.

It was recognized that the Vicon Motion capture system at the Naval Postgraduate School could be used to capture a marksman in detail; capturing up to a hundred frames per second is possible. The Defense Language Institute (DLI) located less than two miles from the Naval Postgraduate School (NPS) possesses an Engagement Skills Trainer (EST 2000) that the Army uses for simulation training for weapon familiarization, target acquisition, and sustainment. The authors' asked, "With both of these systems available could the EST 2000 be used in conjunction with motion capture to record and study movement during weapons fire?" Was the Vicon Motion Capture system the best method to capture this data? By placing the motion capture cameras to provide a nearly three hundred and sixty degree field of view would it be possible to gather posture data during the use of simulation? The EST 2000 simulator measures performance results of weapons use, would it be possible to validate that the EST 2000 is a viable solution to training basic rifle marksmanship? Would it also be possible to receive instant posture feedback and give the shooter a visual depiction of their posture while firing the M-16A2 rifle?

A picture is worth a thousand words, especially when a soldier is a novice marksman and has little or no experience on the use of their individual weapon. As novice marksmen join the Army they are solely dependent on the experience of their drill sergeant and their buddy to their left or right. This results in a range of inconsistencies in training. How much more experience does their "battle buddy" have to actually correct

their deficiencies? The goal is to provide the frame work to create a tool that will allow a trainee to see an accurate representation of what “right” looks like when using their individual weapon and to determine if it is possible to digitally map shooter profiles using motion capture.

C. RESEARCH QUESTION

The Army and Marine Corps have traditionally used these five basic characteristics to measure expert marksmanship: trigger pull, breathing, butt stock pressure, weapon cant, and consistent aiming point. The authors used these basic characteristics of marksmanship to determine a subject’s skill level. This thesis sets out to prove it is possible to determine profiles and whether these profiles affect an individual’s ability to fire a weapon. The author’s experiment using the Army’s Engagement Skills Training (EST 2000) simulator and the Vicon Motion Capture System was able to measure these five characteristics in a very precise manner.

To determine marksmanship profiles the author asked a series of research questions:

- Are profiles clearly visible and distinguishable using motion capture?
- Can one be an expert marksman without having all five characteristics?
- Could a virtual trainer demonstrate what “Right” looks like by showing correct shooting profiles based on motion capture?

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II. BACKGROUND

A. PERSONAL BACKGROUNDS

Major Platte served his first 11 years of service as a Signal officer and has served the last two years as a simulations operations officer (FA57). During this time he has served in Signal leadership positions of increased responsibility from platoon leader, command of three signal companies, Quick Reaction Force Commander, battalion signal officer and Secretary General Staff for the Signal Center and Fort Gordon. His operational and combat deployments include United States Forces Korea (USFK), Quick Reaction Force Commander, Quick reaction force Commander Fort Gordon, GA post 9/11, Common Task Trainer for the 447th Signal Battalion, Range Officer-In-Charge of area #2 in USFK, marksmanship trainer for the Quick Reaction Force Fort Gordon, GA. Major Platte is certified in Cisco routers, local area networks, wide area networks, HF radios, the Joint Network Node, Satellite Communications, etc. He was responsible for all communications for the Commander In Chief USFK for all wartime missions. Major Platte has a Masters degree in Education from Troy State University where he graduated with honors. Following graduation from the Naval Postgraduate School Major Platte will serve as the Simulation Officer for the 2nd Infantry Division in USFK.

Major Powers served his first 15 years of service as an infantry enlisted soldier, infantry officer and has served the last four years as a simulations operations officer (FA57). During this time he has served in infantry leadership positions of increased responsibility from team leader, platoon leader, command of three infantry companies, battalion executive officer and advisor to the Arkansas Army National Guard. His operational and combat deployments include Operation Able Sentry – United Nations Preventive Deployment Forces, Macedonia; Operation Noble Eagle – Implementation Forces for the Dayton Peace Accords, Bosnia; Operation Iraqi Freedom (OIF) I&II - Iraq. During his deployment to Iraq he was responsible for the training of the Arkansas National Guard Thirty Ninth Brigade Combat Team (BCT) on the proper use and employment of their small arms weapon systems, working in the brigade current and future plans cells, and training Iraqi Officers to lead their newly formed units. Before

attending the Naval Postgraduate School Major Powers worked at Fifth United States Army (ARNORTH) located in San Antonio, Texas in this position he served as the Command's FA57 working to improve homeland security using technology to better the commands ability to share information between government agencies and service components. Following graduation from the Naval Postgraduate School Major Powers will serve on the Department of the Army Staff in the G3/5/7 (General Staff – Operations, Plans and Training) responsible for the establishment, funding, and oversight of army simulations programs of record.

B. CURRENT MARKSMANSHIP

During basic training, soldiers are given a fourteen day period of instruction on the use of the M16/M4 Semi-Automatic Assault Rifle. "The M4/M4A1 5.56mm Carbine is a lightweight, gas operated, air cooled, magazine fed, selective rate, shoulder fired weapon with a collapsible stock" (Security, 2008) and is a variant of the well known M16 Rifle that has been employed by the United States military since the Vietnam War. This process takes what is assumed to be a soldier with no previous knowledge of their personal weapon and teaches them the skills necessary to qualify on their individual weapon. As stated in the motivation for writing this paper it is not simply good enough to qualify on your weapon, instead you must become an expert. To achieve the level of mastery needed to properly employ their individual weapon soldiers must have exposure to the weapon systems in a repetitive manner ensuring that they can perform marksmanship tasks without thought in the stressful environment of combat (Lightner, 2008).

C. ADVANCED INDIVIDUAL MARKSMANSHIP TRAINING

Part of the Advanced Infantry Marksmanship Strategy and Standards (AIMSS) is to provide doctrine for not only marksmanship training, but to provide the manner which modern optics and laser designator are mounted on the weapon.

The authors conducted an eye dominance experiment as part of a human factors block of instruction during their tenure at NPS as a preliminary point of departure; although the intended outcome was not achieved it laid the foundation for the question

"what really makes someone an expert marksman?" Every soldier needs to determine which one of their eyes is dominant; this will allow them to be a more effective marksman. To become an expert marksman one must train all of their human traits so that they can better prepare themselves for combat. This proved to be the case during the experiment conducted at the University of Iowa ROTC facility. Subjects who had military experience or who were very experienced shooters all knew which one of their eyes was dominant. The subjects that did not know which one of their eyes was dominant did far worse on the EST 2000. The one subject during our experiment that was right handed and left eye dominant shot 17 out of 40 targets. Identifying one's eye dominance is imperative to become an expert marksman. (Platte & Powers, 2006)

D. USE OF SIMULATIONS FOR MARKSMANSHIP TRAINING

Simulations for marksmanship are used primarily as a partial task trainer, meaning that specific tasks necessary to engage a target with a weapon system are trained using simulation. On initial consideration it might appear that a whole-task trainer would be the preferred solution for a Virtual Environments Trainer (VET) but that is not necessarily the case (Wightman & Lintern, 1985). Because of the desire to build confidence in a soldier on the use of their personal weapon the "whole-task" training is focused on live fire training. It is not currently possible to replicate all the environmental variables that are present on both the firing range and in combat using simulation. It is therefore better to focus on those individual sub-tasks that are necessary when engaging a target.

The military has numerous devices that are currently used to provide simulation for marksmanship training. Although many of these simulators are "sold" as a comprehensive full task trainer, it is the authors' opinion that they should instead be considered partial task training devices. Critical to all simulators is to establish "buy-in" from the individuals using the tool. Leaders responsible for the planning and conduct of simulations training must set the condition for those participating (Lightner, 2008). In order to ensure training is being conducted properly on a simulation device it is

imperative that the event is taken seriously and not merely a video game. The simulator listed below is another systems studied in preparation for the conduct of the thesis research.

The Indoor Simulated Marksmanship Trainer (ISMT) is the United States Marine Corps (USMC) simulator used to conduct marksmanship training when resources are not available for live fire training. ISMT is used while conducting operations on ship while serving in a Marine Expeditionary Unit (MEU), and are used for the Embassy Security Detachments (BG Holcomb, 1998). Many of the functions that are present in the EST 2000 are shared with ISMT; the ISMT places concentration on moving target engagement. The ISMT provides attachments that allow the simulated firing of all issued Marine Corps small arms and crew served company level machineguns. The Marine Corps has used the cost savings associated with the use of simulation to justify acquisition of additional ISMT systems. Applying cost saving to purchase new systems is a common practice of all services in an effort to obtain the required training devices necessary to ensure service members are properly prepared to conduct combat operations. The EST 2000 was used in the study as a test bed for motion capture samples of shooting postures.

The primary goal of training is to perform a given task properly. Motion Capture is useful in allowing the researcher to study in detail the movements of their subject. The military use of motion capture to measure performance is a natural extension of technologies that have proved reliable in sports and industry. Motion Capture of postural positions is made possible through the use of the Vicon Motion Capture system which records digitally the actions of the test subjects.

The use of motion capture to conduct training is an established practice in competitive athletics. The United States Triathlon team used motion capture to prepare for the Beijing Olympics. Using “motion-capture analysis gives our coaches crucial data on how to avoid injury as our athletes are training,” said Scott Schnitzspahn, the performance director for USAT, “and also how we can modify their bikes to cut crucial minutes when racing without sacrificing stamina in their runs” (Competitor Group, 2008). Motion Capture allows the athletes to model their individual movement

characteristics to a far greater level of detail than possible when using standard video processing. Athletes are able to determine their most efficient use of energy and to modify their bicycles to fit them precisely.

The Canadian Army is currently using motion capture to develop training tools for their ground forces. By depicting accurate movements of soldiers it is believed that a positive training effect will occur because the solider will better associate their training with the movements of the on screen avatar. It is the intent of the Army to use the motion capture information to better train their soldiers by providing scenarios that could occur during operational and combat deployments. This technology is currently used in the video gaming industry and is being adapted to military training (Canadian Army, 2006).

E. ENGAGEMENT SKILLS TRAINER 2000

The Engagement Skills Trainer 2000 (EST, 2000) Marksmanship Simulator is the United States Army marksmanship trainer used at Fort Benning, Georgia; Fort Benning is the home of the United States Army Infantry Center and School. (Over the next few years Fort Benning will become the U.S. Army center of Maneuver Excellence. This will consolidate initial ground combat doctrinal training to one primary location.) The EST 2000 provides "initial and sustainment marksmanship training, static unit collective gunnery and tactical training, and shoot/don't shoot training. It supports the following three modes of training: marksmanship, squad/fire team collective and judgmental use of force. The system models 11 small arms and is deployable with its own system shelter. All EST 2000 training scenarios are U.S. Army Training and Doctrine Command (TRADOC) validated" (PEO STRI, 2008).

The EST 2000 is also fielded to numerous National Guard and Reserve Component units throughout the world. The simulator provides an excellent platform to conduct sustainment training for those members of the military who are unable to perform live-fire training on a routine bases. Although, there is no substitution for actually live firing a weapon the EST 2000 provides a degree of realism that is not

possible on simulators of the past. As shown below in Figure 1, the system is used to conduct training in low stress environment allowing soldiers to focus on those specific skills need to engage targets with their individual weapon.

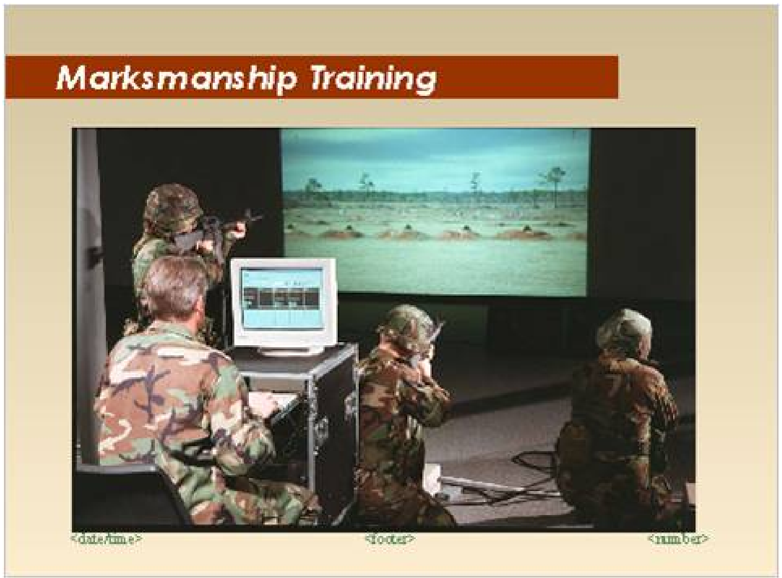

Figure 1. EST 2000 being used by Trainees.

F. MOTION CAPTURE TECHNOLOGY

The most basic question is, “What is motion capture and why is it important to rifle marksmanship?” In their “Motion Capture White Paper" Dyer, Martin, and Zulauf state that motion capture “…involves measuring an object's position and orientation in physical space, then recording that information in a computer-usable form. “Objects of interest include human and non-human bodies, facial expressions, camera or light positions, and other elements in a scene…" (Dyer, Martin, & Zulauf, 1995) the ability to transfer these elements to the computer allow for a detailed study of movement during the performance of tasks.

The use of motion capture to analyze the dynamics of movement while humans perform tasks has allowed a more accurate representation of the small changes that occur which are not visible to the naked eye. This attention to the smallest of changes allows

the researcher to focus on the differences and commonalities of subjects to determine if the establishment of profiles for a given task is possible. Demonstrating the existence and understanding of profiles during the conduct of the studied task is what was attempted during data collection.

Motion capture is currently the best technology available to record and study profiles that are common to different individuals during the performance of marksmanship.

In her study of motion capture, Furniss states that motion capture can be placed in to eight categories, “mechanical, optical, magnetic, sonic, biofeedback, electric field, inertial, and video” (Furniss, 1999) she further breaks down the classification in to active and passive types of motion capture. She goes on to clarify that the active classification includes “magnetic equipment and synchronized lights, if used in optical motion capture, while passive systems most commonly refer to the use of reflective markers in optical mocap” (Furniss, 1999). It is important to note that the use of optical devices can have a much higher cost because of its post processing, which is both time and labor intensive.

Motion capture is also placed into categories that are divided into the areas of “body movement, facial capture, and hand gestures” (Furniss, 1999). This classification became very evident during the experiment because hand gestures were not measured and instead the focus was placed on limb, head, and spinal movements. The goals outlined in Furniss’ paper point out that future motion capture work will include the development and study of performance enhancement. Motion Capture feedback may help allow individuals to increase accuracy of the results by providing the analysis needed to increase performance by combining motion capture with virtual training devices.

The University of Iowa, in partnership with the U.S. Army has developed a life like representation of the human body using virtual imaging. This system is called Santos and provides the medium to show a life like display of the captured data collected while using motion capture technology. Motion capture technology allows the translation of the data into a realistic representation of the human body using a template model captured using the Vicon system. This template is then adapted to the Santos model

developed by the University of Iowa's Center for Computer Aided Design (CCAD), Virtual Soldier Research (VSR) project. The Santos marker protocol allows the translation of the motion capture data to calculate joint angles that are represented using the virtual human model – Santos.

The authors worked in close coordination with the University of Iowa VSR to determine if the captured data using the Vicon Motion Capture equipment could be used to construct a "Virtual Soldier." By using an already funded U.S. Army program it would allow the use of the data to construct the most realistic model possible to display the posture/firing data collected during the experiment. As shown in Figure 2 the Santos model is very detailed in its depiction of the human body.

Figure 2. Santos.

III. SELECTED LITERATURE REVIEW OF MARKSMANSHIP TRAINING

Most of the literature on marksmanship training was focused on establishing the relationship between simulation and live fire training. The focus of the research is on understanding the underlying skill dynamics and what can be done to improve the process of skill acquisition. The number of references used to develop both the concept of the thesis and the application of the systems used were numerous as shown in the bibliography attached to this thesis. Therefore, we selected the most relevant references for our review.

A. COMPLEX SKILL ACQUISITION

An area of great interest to the authors was the study of complex skill acquisition. One of the more useful references for this study was a review article written by Phillip L. Ackerman that appeared in the Proceedings of Human Factors Society – Twenty Seventh Annual Meeting titled *A theory from prediction ability/skill relations: An approach from automatic and controlled processing (1983)*. In this article, Ackerman reviews and discusses studies related to perceptual-motor learning. From this review he proposes a general theory of relationship between abilities and aptitudes based upon an understanding of controlled and automatic processing and various cognitive theories.

The general theory proposed by Ackerman, in part, accounts for the common finding regarding changes in the inter-correlation between early learning trials and late learning trial performance scores. This shows patterns of correlation coefficients change substantially over the course of training. Typical measures of cognitive ability correlate highly with initial training, but then decline in magnitude as training on the operational task continues. Ackerman proposes that one interpretation of this correlation pattern is that cognitive aspects of the task are more influential during early skill learning, and that perceptual-motor components have greater influence as learning progresses. (Ackerman, P. L., 1983)

The theory of controlled and automatic processing proposed by Schneider and Shiffrin (Schneider & Shiffrin, 1977) states that observed changes in operator performance are characterized by “effortful, slow, and error prone” performance during early training periods, and progressively less effort, improved accuracy, resistance to distraction and a greater level of automaticity in performance, as the operator becomes more proficient.

Shiffrin and Schneider further refer to these two forms of processing as controlled processing (CP) and automatic processing (AP). Controlled processing is under conscious control, and easily modified during performance. In automatic processing, task performance is largely unconscious and unfolds much like a stored computer program, and hence is less modifiable during task performance. (Schneider & Shiffrin, 1977) Later studies by Fisk and Schneider (Fisk & Schneider, 1981) indicate that transformation from controlled to automatic performance described by these authors may only be true for tasks that have consistent task elements (in which the operator responds to predictable relationships between perceptual cues and responses).

It is the *consistent components* of a complex skill that stabilize during early training, and the patterns of correlation of these components do not change appreciably over the course of skill development. Skill automaticity therefore reflects the learner’s ability to acquire essential perceptual-motor task components, based in internalized relationships between consistent elements of tasks and relevant perceptual cues.

These concepts of complex skill acquisition are important to the training applications derived from the results of this thesis. These applications include the strategy that instructional designers should attempt to identify cognitive and perceptual-motor components of a complex skill in order to develop effective instructional strategies. For example, it appears most beneficial to offer cognitive approaches early in training, and then shift to perceptual-motor aiding later in the training period. Most importantl,y instructional designers should identify context (environmental) cues that are the most powerful in capturing attention and initiating correct or incorrect responses during later periods of training.

Additional study in complex skill acquisition led to the work of Fisk, Lee, and Rodgers (Fisk, Lee, & Rogers, 1991). In this paper, issues related to the automation of skilled performance are discussed. The study reports findings of experiments investigating the effects of compatible and incompatible automatic processes on performance.

Fisk and his associates amplified an earlier work of Fitts (Fitts, 1962) regarding the automation of skill as a performer moves from novice to expert. Most skill performance progressively improves in speed and precision, as well as a reduction in attention resources required for a given task. A skilled performer appears to perform complex tasks quite effortlessly after substantial practice. Fitts and his colleagues have identified some specific relationships underlying skilled performance that may be useful in establishing principles of learning and performance enhancement. It is strongly implied that the research foundation is well enough established to recommend specific “limits and guidelines" for training.

Key to the research was the identification of guidelines recommended by the author. These include performance improvements (with practice) will only occur for consistent tasks. Second include the type and number of inconsistent task elements limit performance improvement. Third is degree of consistency among stimuli, rules and context are factors to consider in part-task learning strategies. Lastly is the context important element affecting skilled performance, in part, because contextual cues may trigger appropriate or inappropriate automatic performance processes.

Fitts’ study stated that the application of the findings could impact instructional designers should attempt to identify and consider apparent consistencies in the task structure of skills to be trained. Additionally, designers should identify context (environmental) cues that are the most powerful in capturing attention and initiating correct or incorrect responses during acquisition of skilled performance.

A third review of material related to skill acquisition called *Factors in complex skill training* published by the University of Pittsburgh Press, *Training research and education* was written by Paul Fitts. (Fitts, 1962). This paper summarizes his work in the

area of skill acquisition. Fitts' states skill performance is defined as having three key characteristics, spatial-temporal patterning, continuous interactions between input, output and feedback processes, and learning. The basic rudiments of perceptual-motor skill, including basic task taxonomy and characteristics of environmental and internal cues are described. The author discusses the learning of complex skills in terms of "continuous" learning phases, including Cognitive, Fixation, and Autonomous. Paul Fitts was an early pioneer in skill research, and much of the work related to skill acquisition, retention, and measurement of perceptual motor performance is based on his work.

Key to this work was Fitts' identification of the components of complex skills development. These included cognitive which he defined as understanding the structure or nature of the task. Second was perceptual, which was defined as learning what to pay attention to, and what to look for (salient cue recognition and discrimination). Thirdly, Fitts defined physical coordination as the integration of perceptual and motor activities (timing of movement patterns). Lastly, tension relaxation is defined as greater relaxation, and a smoothness and precision with less effort expended. Fitts then went on to define skill development in relation to the conscious analysis and verbalization of tasks and cues which he said are cognitive. Next he labeled the fixative or associative phases of skill development which the correct perceptual-motor patterns emerge. Finally, came the autonomous skill phase which allows the automation of skilled performance, with improved speed, smoothness and accuracy. At this stage of learning there is less conscious control and more resistance to distraction and a shift from external cues to internal (proprioceptive) cues.

Important to the thesis is the application of the findings in Fitts' work. This included the characterizations of skill taxonomy and learning implies various levels of complexity, and progressive levels of skilled performance. Next was the practice of good instructors who understand that teaching complex skills requires different types and levels of information and feedback to the student. So common strategies taken by instructors based upon experience are supported by concepts proposed by Fitts are:

- Provide students with tutorial information regarding the task structure and salient cues to pay attention to.
- Demonstrate correct performance to student, showing correct response sequence and timing.
- Reinforce attention to salient cues during practice sessions, and provide feedback of performance results.
- As skill becomes more automated, provide less coaching and verbal support during task performance.

Lastly, the thesis authors studied a paper by Walter Schneider in his work on Training high-performance skills: Fallacies and Guidelines. (Schneider W., 1985) In this work Schneider makes the point that all trainees do not reach the levels of proficiency desired in many systematic approaches to training, because many training programs are based upon false assumptions about human learning. The Schneider paper also reviews and discusses six of the common training fallacies.

Schneider states that most learning studies are of too short a duration to draw broad generalizations about learning, and training effectiveness. He also concludes that high-performance skills are characterized by three things: the length of time to become competent and proficient at the task, typically high failure and non-completion rate for training, and a considerable performance difference between a novice and an expert. It is important to note that novices often appear "overtaxed" and are easily distracted during performance, whereas the expert appears to perform smoothly and without effort, and is not easily distracted.

Next Schneider purposed that one moves progressively, from novice to expert, the performance changes (in terms of competency exhibited and very likely in terms of the information processing and control tasks performed); while experts make decisions much more rapidly based upon experience, and without much "thinking" or deliberation. Since the composition of the skill itself appears to change over time, then it would seem that the conditions of learning and the training strategy must change as well. Most training programs do not take the changes in skill composition, or a learner's progression from novice to expert into full consideration in arriving at the best instructional strategies for a learner's progression in skill development.

Interesting to his work was the listing of common fallacies to learning. The first such fallacy is "Practice makes perfect." In stating this he shows how some studies indicate that practice on operational tasks does not necessarily improve performance. Sometimes no improvement is observed. It has been demonstrated that practice on consistent elements of a task does improve performance (i.e. consistent relationship between stimulus and response elements). Second is the "Training of the total skill." Training in "real situations" or those with very high fidelity do not necessarily lead to the best training and performance. During performance of a real-world task, the learner (particularly the novice) is often overloaded and may not encode and retain needed information for learning and performance improvement. Often, a learner may improve learning by practicing parts of the total task and then practicing the whole task at a later training progression. Practice on consistent component tasks does improve component skills, and in many situations there are beneficial results (positive transfer) achieved with part-task training of key skill components.

The third fallacy is "Skill learning is intrinsically enjoyable." Because of failure rates in training, it can be improved with better incentives and improved performance feedback. This leads one to believe that "Training for accurate performance" would be a correct goal, but again this is a common fallacy. Instead, in most cases it is better to achieve acceptable accuracy while having the learner pay attention to critical task and important environmental cues. Also over training may be desirable in cases that require a performer to work in a high workload operational environment.

Schneider next shows the fallacy of "Initial performance is a good predictor of trainee and training program success." In reality most initial performance is highly unstable and not a good indicator of ultimate performance of complex skills. The correlation between early performance scores and later performance is often very low. Many studies show that augmented feedback may facilitate performance during training but may actually slow learning. Lastly he argues the final fallacy, "Once the learner has a conceptual understanding of the system, proficiency, will develop in the operational setting." He identifies this because technical programs based substantially on only

classroom teaching typically fail. Additionally, he understands that there is no substitute for hands-on experience with the operational system. Learning a complex skill continues throughout an operator's experience.

The applications gained from this reading include an understanding of the need for trainers to focus on arranging practice on consistent task components. Secondly, was the understanding that complex tasks can be broken down into simpler components for part-task training with positive results. Lastly, is an understanding that trainers should give considerable thought to sequencing of the tasks to be trained, and the kinds of performance feedback that may or may not be appropriate at various learning phases.

B. MARKSMANSHIP TRAINING LITERATURE REVIEW

As stated in the first part of this chapter, most of the literature on marksmanship training was focused mainly on establishing the relationship between simulation and live fire training. Interest in exploring the underlying skill dimensions of marksmanship skill was of primary interest to this thesis. Therefore, we selected material on marksmanship training from the perspective of study findings that appeared to be consistent with their own extensive marksmanship experience, and to extract any information useful in examining the relationships between previous marksmanship experiences, actual shooting performance during EST training, and most of all to identify motion capture shooter profiles capable of discriminating various marksmanship skill levels.

The first such work that met these interests, was a study by Hughes and Nau conducted on the effectiveness of the EST 2000 for use in training heavy weapons (Hughes & Nau, 2007). This study was done for the TRADOC analysis center with the intent to examine and test the capability of the EST as a substitute for live fire training for heavy weapons (Browning Machine gun .50 caliber, M2 and the MK19 4-mm grenade machine gun). The study compared soldiers training with the EST 2000 to those undergoing training on a live fire range. Experimental methods entailed dividing the trainees into three groups (EST only; EST and some live fire; and familiarization live fire training only). Both trainees and instructors completed a survey that evaluated the strengths and weaknesses of each training method. The study concluded that EST could

help maintain skills, in the absence of live fire training due to ammunition shortages. The study authors warned that exclusive training on EST, <u>without the benefit of live fire practice</u> was not advised.

Of note, this report mirrored many of the comments made to the thesis authors concerning the use of the EST 2000 in training by COL Gregory Kane, Commander of the 197th Infantry Brigade of Fort Benning, Georgia. COL Kane is the proponent of marksmanship training for the Army. He stated his belief “that simulations play a vital role in both the initial portion of Basic Marksmanship training and in unit's marksmanship sustainment programs.” He also went on to state that he “… firmly believes that simulations (EST 2000) are a great resources and efficient tools for units to sustain marksmanship proficiency.” What is most important to note is his final comment, “I have also categorically rejected all calls in the past (and now) that simulations replace live fire "trigger pulls" in an effort to save money or reduce range requirements. The current capabilities of the EST 2000 to replicate grouping and zeroing; field fire; record fire qualification or small unit engagements are outstanding and afford the unit commanders the ability to train Soldiers and teams in a multitude of scenarios. Simulators do not however, replicate the noise, environmental hazards, and stress associated with putting Soldiers on a range and firing live ammunition” (Kane, 2008).

“In short, simulators are a great augmentation, but can never fully replace live fire in either BRM or sustainment programs” (Kane, 2008). COL Kane’s statements represent his tremendous experience as a combat commander and his training responsibility to all U.S. Army soldiers.

Key to the findings of Hughes and Nau is that the use of a trainer to substitute for live firing practice of heavy weapons was found to be an effective means to practice when live firing was not possible due to ammunition shortages and other constraints. It is important to note that the study concluded that some combination of EST and live fire training is the best option. However, the thesis authors were unable to garner any specific guidelines for EST utilization or instructional strategy.

The next source studied was a report conducted by Murphy, Farr, and Loviscky in January of 2007. The *Study to quantify the benefits and cost of simulated versus live-fire training at USMC ranges: Final report outline* (Murphy, Farr, & Loviscky, 2007). This study discusses the various kinds of US Marine Corps training approaches to teaching rifle marksmanship, including classroom instruction, simulation training, dry fire shooting, inert ordnance or simulated munitions, and live fire ranges. In the report the authors attempted to determine the "best mix" of training that would result in the most effective training combination, and meet needed cost efficiencies. This report included an excellent review of the rifle marksmanship training sequence that is used during new recruit training, advanced training for infantryman, and annual rifle marksmanship qualification training required for all Marines. The use of the Indoor Simulated Marksmanship Trainer (ISMT), various other training technologies, and live fire range training are briefly summarized. Following a review of these various training approaches, and numerous training effectiveness studies, the article authors concluded that individual weapon system trainers, like ISMT, seem to be effective because it was demonstrated in a number of studies that there was a "consistent relationship between simulation shooting scores and live-fire shooting scores." It was also stated that simulators were most useful in training relatively inexperienced trainees.

Key topics in this article included a discussion of the relationship between marksmanship simulators and live-fire performance, but it is important to understand the basis for this conclusion on a review of the literature, and not on completing any additional training transfer studies. The thesis authors found use of the references of key literature in simulation training effectiveness and the time period studied for the article, 1978 to 2006 to be useful to their research and study of marksmanship.

A technical report for the U.S. Army Research Institute for the Behavior Sciences written by Smith and Hagman in 2000 was studied next. This report is named, *Predicting rifle and pistol marksmanship performance with the Laser Marksmanship Training System: Technical Report 1106* (Smith & Hagman, 2000). The study objective was to demonstrate utilization of the U.S. Army's Laser Marksmanship Trainer (LMTS) for teaching basic marksmanship skills (steady position – stock weld, aiming, breath control,

and trigger squeeze). The study included training on the LMTS and development of regression equations that were successful in predicting success during later rifle range qualification tests. The equations were not useful in determining level of qualification differences (i.e. marksman, sharpshooter, and expert). The primary use of the regression model was to determine the need for remedial training for low scoring trainees. LMS dry-fire practice was recommended over the Blazer option (recoil simulation), because the Blazer did not add any significant predictive value to the regression model.

One finding from the Smith and Hagman study was that the LMS shooting scores obtained from U.S. Army trainees proved useful in predicting final qualification or non-qualification outcomes. The study data also showed the value of the LMS trainer for teaching basic marksmanship skills, but was limited to use on the U.S. Army pop-up target qualification course. It was also noted that the Blazer (sound-recoil replicator) was determined to be of no training value based on regression analysis.

Our last source for reference was conducted by a fellow NPS graduate who used the ISMT to conduct a study titled *A training transfer study of the Indoor Simulated Marksmanship Trainer* (Yates, 2004) In this study Yates provided contrast to a number of earlier studies that demonstrated positive relationship between simulated rifle marksmanship training scores and live fire qualification scores. The Yates study did <u>not</u> find any improvement in US Marine recruit trainees who received Indoor Marksmanship Simulation Trainer (ISMT) shooting practice prior to live rifle shooting qualification scoring. The Marines who received ISMT training were compared to a control group who received only dry fire training prior to performing live fire qualification on the shooting range.

This experiment and other data collected by Yates, led him to conclude that "no evidence was found to suggest that ISMT can be used as an independent training system to fully train marksmanship, without the benefit of "expert instruction" or a pre-existing level of shooting experience."

One key objective of the Yates experiment included the experimental question regarding an attempt to determine if ISMT could be as effective as conventional marksmanship training given equal training time and supervision to the trainees. This part of the study allowed him to take advantage of the ISMT which permits training in a benign, controlled environment, and an environment in which shooters can receive "immediate round-to-round feedback". It was also determined that the ISMT was useful in replaying a real time trace of the shooter's point of aim during trigger pull and recoil recovery, in addition to accuracy and precision (shot grouping). Yates was careful to use the same instructors for each group in an attempt to control for any variation due to instructor or instructional method. Unfortunately, that during the live fire qualification testing for the experimental (ISMT) group there were significant weather effects present (wind and rain), which may have affected their qualification scores. The weather effects may be the main reason that a positive relationship between ISMT training and live fire scores was not found.

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IV. METHODOLGY FOR INITIAL VALIDATION STUDIES

A. MOTION CAPTURE VALIDATION EXPERIMENT ONE: NPS

A pilot study was conducted at the Defense Language Institute to validate the follow-on experiment taking place at the University of Iowa. The purpose was to ensure the proposed motion capture methodology was viable for use with the EST 2000. The Vicon Camera system required testing to ensure the infrared lighting to be used in the study would not interfere with the laser devices used to register simulated shots fired using the EST 2000. Vicon cameras use infra-red lights that turn off and on, in a strobe light type manner, at an extremely rapid rate and then reflect this light back to the camera lenses using reflective markers. The reflected light does not interfere with the vision of the test subjects because of the high frequency; the need for a high frequency is discussed later in more detail. The technical specifications of the Vicon Motion Capture system can be found using the links provided in Appendix 6 of this thesis.

The EST 2000 uses a laser beam located in the barrel of the weapon to mark the simulated strike of the round on the screen. The initial concern was that the lighting of the Infra-red Vicon cameras would disrupt the accuracy and marked performance of the EST 2000. The simulator records the number of hits or misses; the system also records specific characteristics such as butt stock pressure, weapon cant, aiming point, trigger squeeze, and overall performance. The final field of view seen by the subjects is shown in Figure 3.

Two experienced male subjects using the simulator completed fifteen iterations of the qualification pop-up range. The first five engagements were conducted without the Vicon cameras active. The EST 2000 recorded the subject’s normal performance. The second five iterations used were with the cameras set at a low hertz update rate so that the cameras were flashing and could be seen by the human eye. It was imperative to determine the level of usability of the camera system because the low hertz update rate

made one subject became nauseated. During the final five iterations was with the hertz level turned up to a hundred frames per second. The subjects had no issues at the higher hertz level.

The results were that the two firer's scores were almost identical throughout all of their firing sequences while one subject scored higher with the cameras turned on; this confirmed that the cameras would not disrupt the planned experiment at the University of Iowa. This test was critical in confirming the design of experiment.

Figure 3. Clear Line of Sight for the Marksman.

The second part of the validation experiment was actually placing the Santos marker protocol on a subject and recording the results using the Vicon Motion Capture system. Next a test was conducted to determine if the Santos model was going to be precise enough to display the needed aspects of the subject's posture. During this process the Santos marker protocol set was tested. After calibrating the cameras and putting all of the markers on the subject he was instructed to lie in the prone supported position. An experienced male shooter then fired on the EST 2000 with the motion capture suit on.

The result showed the markers on the computer screen, but converting the data to create a Santos .vsk (.VSK is the file format that the motion capture data) posture was difficult. Some of the front markers could not be captured by the cameras as the subject was lying in the prone supported position. The prone supported firing position was used

because it requires less training to performing the shooting task. Positions such as the standing, kneeling, and prone unsupported, each require a greater degree of skill to shoot accurately, and are considered more advanced techniques. Since this thesis sought to study only basic rifle marksmanship the researchers chose to use the most basic of shooting positions. As the subject lay in the prone supported position the cameras were unable to make out joint angles in the wrists, feet, shoulder, spine, and sternum. It was determined that additional markers were needed to convert the data into a usable Santos .vst (.VST is the template data structure used to identify each of the individual markers used by Santos). Eighteen extra markers were used to allow for the development of a Santos .vsk and accurately depict a virtual avatar of the subject firing during qualification. With the knowledge gained from this rehearsal important insight was gained of the Santos marker protocol and provide feedback to the research team at the University of Iowa's Virtual Soldier Research Center.

B. MOTION CAPTURE VALIDATION EXPERIMENT TWO: UOI

The authors conducted another validation experiment at The University of Iowa's Virtual Soldier Research Center (VSR). A site recon of the experiment location at the ROTC department was necessary and discussion of any hardware and software issues to ensure compatibility with the VSR motion capture system and the EST 2000 at the ROTC department. The University of Iowa staff was made aware of the need to add additional markers and consulted on the proper adjustments to the Santos protocol. During the NPS rehearsal the software was version 2.5 of the Vicon motion capture system; the Virtual Soldier Researcher's Vicon Motion Capture equipment used the older 2.0 version of the software package. No significant issues were apparent between the two versions of the software.

The University of Iowa's team is very experienced with the Vicon Motion Capture system and has used it for numerous other projects with outstanding results. The VSR team also use a different kind of camera set-up then used during the rehearsal conducted at NPS. The University of Iowa uses twelve motion capture cameras while the NPS set up uses eight Vicon cameras for data collection. The concern was that twelve

cameras might be too many and could possibly obstruct the view of the shooter while firing on the EST 2000 Simulator. As shown in Figure 4 the number of camera had no impact in the subject's ability to see the screen.

Figure 4. Subject's View of Screen.

The Vicon cameras used at NPS are different as they have a 60 degree angle of coverage; whereas, the University of Iowa cameras have a 75 degree angle of coverage. The University of Iowa uses 8mm marker sets. The first study at NPS used the 14mm marker set. As shown below in Figure 5 there is a significant size difference in the two marker sizes. The smaller markers actually allowed for more accurate measurements because the cameras registered less reflected light when recording marker location.

Figure 5. Marker Set Comparison.

During the VSR site reconnaissance and coordination meeting with twelve members of the Virtual Soldier Research team four days were spent by the researchers to learn how the VSR team conducts research. This time was also spent understanding how the process of data transfer from motion capture to Santos was conducted, thus allowing the captured data in motion capture to be shown in Santos.

A great deal of time was spent learning the University of Iowa's Motion Capture equipment and how the VSR team conducted their post processing of Santos; the underlying code is written in C to translate the data using inverse kinematics. The VSR team talked to the authors about the process, protocol, and software used at UOI. As a capstone exercise an actual Motion Capture practical demonstration was conducted from start to finish. A detailed description of the validation process used by the VSR is provided in Appendix 4. Time was spent learning data post processing, created and exported C3D to ASCII using VICON workstation (.csv), ran inverse kinematics code, animated the results in the Santos Virtools environment, and had questions and discussion time as a wrap-up in the evening.

This trip was critical in validating the experimental design and actually seeing the motion capture equipment and experiment site. At the conclusion of the visit with the Virtual Soldier Research Center there was complete confidence that the idea was viable.

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V. METHODOLOGY FOR FINAL EXPERIMENT

A. MARKSMANSHIP CHARACTERISTICS

The characteristics of marksmanship are those fundamentals that are considered critical to engaging a target with an accurate shot from a rifle. Each of the characteristics is defined by the military marksmanship manuals of the U.S. Army and United States Marine Corps and summarized into comprehensive documents by Dr. Anthony Ciavarelli in his work on marksmanship training and expertise. (FM 3-22.9 Rifle Marksmanship, 2008; Marine Corps, 2001; Ciavarelli, 2008) While not all of the listed characteristics were used during the experiments, each of these must be understood to fully understand the process of properly engaging a target with a rifle. Listed in the following sub-paragraphs, are each of the characteristics and their definitions. (Baker, 2004)

1. Sight Alignment

Sight alignment is the relationship between the front and rear sight post. This relationship is the most critical to aiming and must remain consistent from shot to shot. A sight alignment error results in a misplaced shot. This error grows proportionally greater as the distance to the target increases.

2. Sight Picture

Sight picture is the placement of the tip of the front sight post in relation to the target, while maintaining sight alignment. Correct sight alignment but improper sight placement on the target will cause the bullet to impact then target incorrectly on the spot where the sights were aimed when the bullet exited the muzzle. To achieve correct sight picture, one must place the tip of the front sight at the center of the target while maintaining sight alignment.

3. Stock Weld and Butt Stock Pressure (Stability and Canting)

Stock weld is the point of firm contact a between the cheek and the stock of the rifle. The head should be as erect as possible to enable the aiming eye to look straight through the rear sight aperture. The eye functions best in its natural forward position. Changing the placement of the cheek up or down on the stock from shot to shot may affect the zero on the rifle due to the perception of rear sight aperture. A consistent and proper stock weld is critical to the aiming process because it provides consistency in eye relief, which affects the ability to align the sights. Holding the weapon firmly to the shoulder helps maintain this consistent alignment of the head to the weapon.

4. Eye Relief

Eye relief is the distance between the rear sight aperture and the aiming eye. Normal eye relieve is two to six inches from the rear sight aperture. The distance between the aiming eye and the rear sight depends on the size of the individual firing the weapon. While eye relief varies slightly from one position to another, it is important to have the same eye relief from all shots fired from a particular position. If the eye is too close to the rear sight aperture, it will be difficult to line up the front sight post in the rear sight aperture. Moving the eye back from the rear sight aperture will make the aperture smaller and allow the tip of the from sight post to be easily lined up inside the rear sight aperture. If the eye is too far from the sight aperture, it will be difficult to acquire the target and to maintain a precise aiming point.

5. Breath Control (Breathing)

Proper breath control is critical to the aiming process. Breathing causes the body to move. This movement transfers to the rifle making it impossible to maintain proper sight picture. Breath control allows the individual to fire the rifle at the moment of least movement. It is critical that individuals interrupt their breathing, at a point of natural respiratory pause, before firing a long-range shot or a precision shot from any distance. A respiratory cycle lasts four to five seconds for most people; inhaling and exhaling each require about two seconds. A natural pause of two to three seconds occurs between each

respiratory cycle. The pause can be extended up to ten seconds. During the pause, breathing muscles are relaxed and the sights settle at their natural point of aim. To minimize movement, individuals must fire the shot during this natural pause.

6. Trigger Control

Trigger control is the skillful manipulation of the trigger that causes the rifle to fire without disturbing sight alignment or sight picture. Controlling the trigger is a mental process, while pulling the trigger is a physical process.

7. Grip

A firm grip is essential for effective trigger control. The grip is established before starting the application of trigger control and it is maintained through the duration of the shot. To establish a firm grip on the rifle, the marksman must position the “V” formed between the thumb and the index finger on the pistol grip behind the trigger. The fingers and the thumb are placed around the pistol grip in the location that allows the trigger finger to be placed naturally on the trigger and the thumb in position to operate the safety. The grip should be firm enough to allow manipulation of the trigger straight to rear without disturbing the sights. After obtaining sight picture, the marksman applies a smooth, continuous pressure rearward on the trigger until the shot is fired.

8. Follow Through

Follow through is the continued application of the fundamentals until the round has exited the barrel. In combat, follow-through is important to avoid altering the impact of the round by keeping the rifle as still as possible until the round exits the barrel.

9. Recovery

It is important to get the rifle sight back on the target for another shot. This is knows as recovery. Shot recovery starts immediately after the round leaves the barrel. To recover quickly, an individual must physically bring the sight back on the target as

quickly as possible. The body's skeletal structure provides a stable foundation to support the rifle's weight. A weak shooting position will not withstand a rifle's repeated recoil when firing at the sustained rate or buffeting from the wind.

10. Bone Support

To attain a correct shooting position, the body's bones must support as much of the rifle's weight as possible. Proper use of the sling provides additional support. The weight of the weapons should be supported by bone rather than muscle because muscles fatigue whereas bone do not. By establishing a strong foundation for rifles utilizing bone support, the marksman can relax as much as possible while minimizing weapon movement due to muscle tension.

11. Muscle Relaxation

Once bone support is achieved, muscles are relaxed. Muscular relaxation helps to hold the rifle steady and increases the accuracy of the aim. Muscular relaxation also permits the use of maximum bone support to create minimum arc of movement and consistency in resistance to recoil. Muscular relaxation cannot be achieved without bone support. During the shooting process, the muscles of the body must be relaxed as much as possible. Muscles that are tense will cause excessive movement of the rifle, disturbing the aim. When proper bone support and muscular relaxation are achieved, the rifle will settle onto the aiming point, making it possible to apply trigger control and deliver a well-aimed shot.

12. Natural Point of Aim

The point at which the rifle sights settle when in a firing position is called the natural point of aim. When in a shooting position with proper sight alignment, the position of the tip of the front sight post will indicate the natural point of aim. When completely relaxed, the tip of the front sights post should rest on the desired aiming point.

B. PERFORMANCE MEASURES

Of the above listed marksmanship characteristics, only five of those were used during the conduct of this thesis experiment. The reason for picking these specific characteristics is because the simulation system used, the EST 2000 provided the experimenters with data that was measureable in some manner. The five chosen were Trigger Pull, Breath Control (Breathing), Aiming Point (Sight Alignment and Sight Picture), Butt Stock Pressure (Grip), and Weapon Cant. Of these five only one characteristic was "objective" in nature, this characteristic was Weapon Cant. The others were "subjective," but multiple points of reference were used to establish the score assigned to each.

1. Objective Data

Weapon cant was a data point taken off the EST 2000. A score was given to the cant of a weapon based on how the individual held the weapon in relation to a designated center point. This center point was considered straight up and down by the simulator. A score was assigned based on the degree of change from the zero position of vertical. Since an actual measurement score was given to this data point the experimenters were able to provide a direct transfer of score for analysis.

2. Subjective Data

The four additional points of study were assigned scores that were given in relation to the subject's ability to score hits with their weapon during qualification, or lack of qualification, on the part of non-qualifying subject, and the registered feedback on the EST 2000. It was possible to use the EST 2000, motion capture analysis/observations, and the judgment of the subject matter experts to quantify the four remaining characteristics into groups. All of these scores were later analyzed against the dependent variable of marksmanship score.

a. Trigger Pull

The experimenters assigned the following "grade" to the subject based on feedback from the EST 2000. The EST 2000 showed the amount of pull on the trigger before and after the time of the simulated round leaving the barrel of the weapon. Ratings given to this characteristic were rated from one to three with the larger number rated "better." It the subject was unable to maintain the point of aim while pulling the trigger, meaning the round did not even hit the target; the subject was assigned a score of one. If the subject was able to keep the strike of the round on the target, but did not hit within the 5mm need to be considered "grouped" then the score was assigned as "average" and assigned a score of two. The remaining score was assigned as a three, meaning the subject both hit the target in the desired location and did not move the sights when the trigger was pulled.

b. Butt Stock Pressure (Grip)

The experimenters assigned grades of four categories to the characteristic of Butt Stock Pressure. This measurement was used to illustrate grip by showing how much backwards pressure the subject was placing on their shoulder during the conduct of firing the weapon. The higher score was considered better. The EST 2000 showed pressure against the butt stock on a scale of 0 – 100. The experimenters used the following criteria: below 69 was rated as "bad" and given a score of one; 70 – 79 was rated as "medium" and given a score of two; 80 – 89 was rated as "average" and assigned a score of three; lastly was 90 – 100 which received a core of "good" and given a score of four.

c. Breathing (Breath Control)

The experimenters assigned grades in four categories for breathing to allow comparison of performance with the final score on the weapons qualification test. The higher the number the better the performance of the subject with scores ranging from one to four. In this case no subjects were rated with a score of two because of the great disparity of scores in relationship to breathing. Although some individuals were able to score at an acceptable level, those who maintain control of their breathing were much

more likely to perform better, and hence were assigned a higher score. The EST 2000 showed the subjects breathing pattern during the entire conduct of fire. Those who received a score of one were considered “bad” on their performance using the simulator, and were unable to maintain sight alignment for any amount of time, and if they did strike the target, it was with little, if any, consistency. Those who scored the average rating of three were able to maintain the aim on the EST 2000, but if the strike of the round was in different places on the target, and a consistent center of mass hit, it was not recorded. The participants who scored a four were both able to engage the target in a consistent manner, but were additionally able to hit the target center of mass with each round.

d. Aiming Point

The experimenters assigned grades using four categories for aiming point. Aiming point for the context of this experiment represented sight alignment and sight picture. As will be discussed in the recommendation portion of the thesis it was difficult to evaluate sight picture using the EST 2000 or the motion capture process. Instead the researchers had to use observational analysis in conjunction with the feedback of the EST 2000 to determine if the subject was indeed aiming in relation to the target. A score of one represented the subject’s inability to maintain a consistent strike point of the rounds in relation of one round to the next round of fire form time of trigger pull to strike of the round on target; many times the rounds did not hit the target at all for the rating of one. No subjects were rated as a two because the criteria for this evaluation were not met by any participant. The scale for this rating was only the ability of the subject to keep the strikes of the rounds on the target, but failing to keep the shots in a consistent 15mm grouping at center mass. The rating of three was given to those subjects who hit the target in a consistent manner, but were not able to maintain the 5mm shot grouping at center mass of the target. Those given the rating of one were both able to engage the target consistently, but when the round hit, it was in the 5mm striking range. When

the target was missed, some other factor played a major part in the strike of the round. One possible reason for this finding could be that the participant did not see the target presented and simply did not engage the target.

C. SUBJECTS

All participants were volunteers from the University of Iowa. They included six foreign national students, two ROTC cadets from the University of Iowa, and nine resident students currently enrolled at the University of Iowa. Their experience ranged from very experienced to no experienced. There were two females and fifteen males.

The subjects selected for study were taken from three primary groups of participants. These three groups represented those unable to qualify, those who scored from 26 to 25 on the qualification (these scores represent the qualification level of marksman and sharpshooter), and those subjects who scored from 36 to 40 on the weapons qualification test.The score of 36 and above is considered expert on the U.S. Army weapons qualification test, and since part of the thesis was to prove the differences between beginner, medium, and expert shooters, this further supported this part of our thesis.

D. RESEARCH QUESTIONS AND HYPOTHESES

The three research questions proposed for this thesis were:

- Are profiles clearly visible and distinguishable using motion capture?
- Can one be an expert marksman without having all five characteristics?
- Could a virtual trainer demonstrate what “right” looks like by showing correct shooting profiles based on motion capture?

1. Individual Measurements

This is a re-statement of those questions listed earlier in the work, but it is important to understand that the first and third questions are more subjective in nature and are not necessarily experimental in nature. The second question can clearly be resolved using an experiment to determine if the characteristics of marksmanship, as stated by the military, are truly critical for the performance of expert marksmanship.

The first research question is distinguishable by capturing the details of movement, and determining if any patterns are distinguishable and/or comparable to those who perform at the same level of qualification as those who share similar profiles. By using motion capture it is possible to record at high speeds the movements of individuals performing task. The second question requires a hypothesis driven by empirical research. In the case of this thesis the researchers proposed the following null hypothesis: The characteristics of marksmanship are unrelated to expert marksmanship. The outcome of the experiment provided information to either reject or fail to reject this null hypothesis. Question three ask whether virtual trainers can be used to demonstrate what "right" looks like for those performing marksmanship training, and to determine if it is possible to capitalize on motion capture technology to accurately demonstrate "right" to the trainee.

2. Composite Measurements

After careful study of the second thesis question, it was determined that failure to reject the null hypothesis for independent measures was the conclusion. If the characteristics of marksmanship are by themselves not critical for the conduct of expert marksmanship, is it possible that taken together they are needed for expert marksmanship? This led to the testing of a second null hypothesis which stated that the composite characteristics of marksmanship are unrelated. Additional analysis was conducted using a composite score analysis that allowed the researchers to reject this hypothesis.

E. ANALYSIS PERFORMED

The analysis performed included multiple regression and ANOVA tests. The dependent variable used throughout the data analysis was the marksmanship qualification score. All data collected was used in an effort to specifically determine if five specific characteristics of marksmanship studied in the experiment are necessary to perform at the level of expert. This statistical testing was performed to determine the value of marksmanship characteristics based on the two research questions purposed.

Regression was used during this study in an effort to determine if the characteristic of marksmanship were related and if so was there a particular characteristic of the five studied that was more valuable than the others. Additionally, ANOVA testing was conducted to further determine the possible statistical significance of the results.

F. EQUIPMENT AND INSTRUMENTATION

1. Motion Capture System

The Vicon Motion Capture Camera System T160 was used for collecting all motion capture data used in this study. The T160 has a resolution of 16 megapixels, captures 10-bit grayscale using 4704 X 3456 pixels and can capture speeds of up to 2,000 frames per second and is capable of capturing 120 frames per second at full frame resolution (16 Megapixels). More detail on camera specifications can be found in Appendix 7.

2. Human Kinematics Measurement System (Santos)

Santos was developed by the Virtual Soldier Research (VSR) Program at The University of Iowa. The present capabilities of Santos include whole-body posture prediction, advanced inverse kinematics, reach envelope analysis, workspace zone differentiation, muscle force and stress analysis, muscle fatigue prediction, simulation of walking and running, dynamic motion prediction, physiologic assessment, a user-friendly interface, a hand model and grasping capability, clothing modeling, thermo discomfort assessment, muscle wrapping and sliding, whole-body vibration analysis, and collision avoidance. More detailed specifications of Santos can be found on the web at the University of Iowa, Center for Computer Aided Design.

3. Engagement Skills Trainer (EST) 2000

A description of the EST 2000 is provided to allow the reader to have an understanding of the physical layout and the capabilities of the system. This simulator is designed to provide immediate feedback on a soldier’s use of their individual weapon in a simulated environment. The EST 2000 provides initial and sustainment marksmanship

training, static unit collective gunnery and tactical training, and shoot/don’t shoot training. It supports the following three modes of training: marksmanship, squad/fire team collective and judgmental use of force. The system models 11 small arms and is deployable with its own system shelter.

> The EST (Engagement Skills Trainer) 2000 consists of a movie theater size screen (but at ground level, not raised) with back projection target situations displayed as interactive movies. The troops use rifles, pistols and machine-guns that are actual weapons, but modified to fire "electronic bullets, and, via a thin cable, use a pneumatic system that provides recoil as well. There is a sound system to depict the sound of the weapons firing, as well as a computer controlled tracking of ammo fired, letting users know when they have to reload.
>
> Because it is a simulator, it captures a precise record of exactly where the soldier’s weapon is aimed, how well the soldier pulls the trigger, and how long it takes to find and fire at the next target. This enables instructors to much more rapidly detect problems troops are having, and correct them. Tests have shown that you can take people with no weapons experience, put them through four hours of EST 2000 training, and take them to a rifle range, and they will be able to fire accurately enough to exceed military requirements.
>
> The simulator can be used for training troops in ways that are impractical using live ammo. For example, when used for "shoot/don't shoot" situations, the appropriate visuals (an enemy, soldier, or a civilian) are shown on the video screen. Soldiers train in a group, positioned as they would be in a real situation. The scenario then plays out, allowing the troops to practice when they should shoot, and when they should not. Training can be for day or night scenarios, and for a wide variety of situations.
>
> Each EST 2000 system can train 800-1,000 troops a month. An instructor runs the software that controls the system, and the training. Troops who have been through the "shoot/don't shoot" simulator report that facing the real thing was a lot easier, less bloody, less stressful and less dangerous as a result. Troops who practice other types of combat situations on EST 2000 also report excellent results in combat. The simulator not only provides better training, but does it at less cost, and is much safer. Much like the payoff with flight simulators” (Strategy, 2008).

G. EXPERIMENTAL PROCEDURES

1. Setting up Motion Capture Equipment

Figure 6. Tri-Pod Camera Set up.

The first step of the experiments was setting up the twelve Vicon Motion Cameras around the EST 2000 platform. The platform was originally setup width ways, which allowed the subjects feet to hang over the end of the platform as they lay in the prone supported firing position. The decision was made to rotate the platform 90 degrees so that it would accommodate the tallest subject without their legs hanging over the side. This allowed for the subject to get in the proper prone supported firing position which better represented the conditions presented to a trainee during basic training. All cameras were on tripods that were 70 inches tall and were able to capture all of the floor space occupied by the subject. Figure 6 shows the placement of three tri-pods in relation to the firing platform.

Figure 7. Author Calibrating Cameras.

The second step was to calibrate the ten cameras used to capture the data for the experiment. In order to do this successfully a wand with markers on it was waved in front of each camera. As shown in Figure 7 the wand was the 240 millimeter wand designed for motion capture calibration. This step is critical because the Vicon software must be told what size wand is used to allow proper camera calibration. This allows the cameras to identify the capture space and also allows for the cameras to know the location of the other cameras in relationship to themselves in 3D space. The Vicon motion software then tells the computer when all of the cameras have been calibrated and are working properly. As the wand is waved a blinking light on each camera turns from yellow to a solid green light which indicates a sufficient amount of data has been collected by the camera to allow successful calibration. The camera was then ready to capture data at a rate of 100 frames per second. The setting up of all of the equipment and calibration took approximately two hours.

2. Receive and Brief Subjects

Figure 8. Author Pre-Briefing Subjects at the University of Iowa.

As shown in Figure 8, the third step was to receive subjects and have them fill out and sign the volunteer statement, questionnaire (see Appendix 5) on their prior weapon experience, and then receive minimal marksmanship training. All of the subjects were civilians with the exception of two ROTC cadets from the University of Iowa. The subjects were shown proper sight picture, aiming point, how to hold the weapon, and how to properly lock and load the M-16A2 rifle. (Locking consisted of inserting the ammunition magazine fully in the weapon. Loading required pulling the charging handle to the rear and releasing chambering a 5.56mm round in the weapon.) Questions were then answered about firing sequence on the EST 2000, but experimenters gave minimal feedback on specific details on aiming, breathing, trigger pull while firing the M-16A2; the lack of information provided to the subjects attempted to prevent a training effect.

3. Anthropometric Measurements

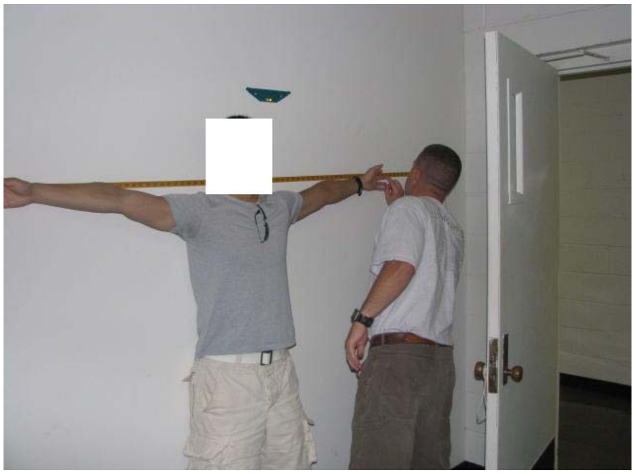

Figure 9. Author Measuring Wingspan.

Figure 9 shows the forth step of the experiment, measuring the subject's "wingspan" to provide data to determine later if there was any correlation between subjects arm length and problems establishing a proper aiming point with the rifle. This measurement was not calculated into this thesis, but the researchers believe that collecting this data point could potentially provide useful data for follow-on research. An interesting fact about motion capture is that it gives all of the subject's anthropometric data from the marker set worn while they fire. As seen in the Figure 10, the marker set is limited to joint angles; this prevented the measurement of hand and finger length.

Figure 10. Back View of Marker Layout.

It is important to note that the marker set covers most joint angles on the subject's body. This is critical when doing motion capture on human subjects because it allows a "life like" replication of human movement. For the experiment only the top half of the subject's posture was studied, but each marker was mapped allowing data input into Santos for whole body mapping. Figure 11 shows the subject in the prone supported firing position with the marker set on the M16-A2 rifle to measure weapon alignment and steadiness. Creation of avatars is necessary because it allows the researchers to define specific objects without interfering with the motion capture of another. In the case of creating a M16A2 avatar it would have allowed the users to use the virtual points on the weapons as static points that would not move because of movement of material or skin. It would have then allowed measurements of body markers in relation to the fixed points on the weapon. These markings would have then provided a second set of points for measurement studies. Instead of only having measurements in relation to the point of origin in the 3D environment or point movements in relation to other points; another set of points would have allowed the researchers to take additional measurement for comparison.

The authors were not able to create two avatars from the marker set to separate the subject and the rifle. The lack of avatars limited the ability to analyze the subject's posture in a more detailed manner because it was not possible to compare the posture with the alignment of the rifle. The motion capture data is very precise and if an avatar for the weapon was built it would have allowed analysis of posture and weapon alignment frame by frame.

Figure 11. Subject in Prone Support Position/Weapon Marked.

4. Marker Placement Modifications and Challenges

The most challenging part of the experimental set up was the placement of additional markers. Because the Virtual Soldier Research lab had previously established the Santos marker protocol, the placement of markers required precision and consistency. The marker protocol used for Santos is discussed in detail by the UOI VSR team in numerous papers that are available online at the CCAD. Placing additional markers on the subject would later require modifications to the post processing which will be discussed later in detail.

Velcro tape was used on the subject to allow placement of the markers on the skin. This allowed the covering of every joint angle to include the head; the Velcro also ensured that the markers remained in place. This soon turned out to be a serious challenge as shown in the picture below. As shown in Figure 7, some of the subjects required additional tape to ensure the markers stayed in place because of perspiration. When the subjects would perspire it would cause the markers to fall off. This soon caused a serious time constraint.

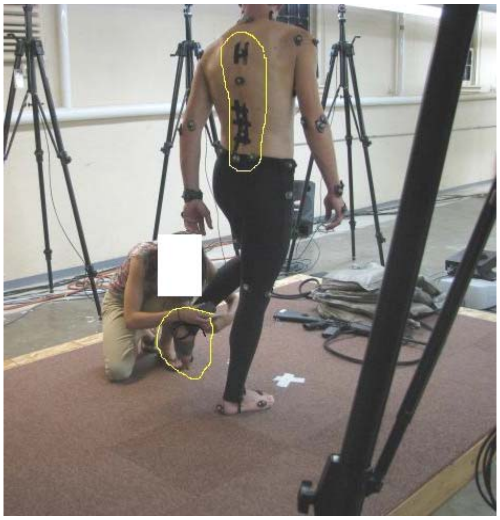

Figure 12. Challenges of Marking on Skin.

The solution to the problem of markers falling off was having the subject wear a motion capture top which enabled the marker set to stay attached to the material using Velcro. (The full motion capture suit is shown in Figure 13 – shown are the members of the motion capture research team at NPS for the marksmanship profile study.)

Figure 13. Full Body Suit Marker Set.

During the firing sequence the authors would lie down next to the subject and visually identify flaws in their shooting technique which were documented and compared to the motion capture data (shown in Figure 14). This process helped organization and

allowed confirmation of subject actions as the data was processed. Certain characteristics that the motion capture data was unable to identify were noted by the observer; for example, did the subject fire with one eye shut or scan for targets using both eyes open which would possibly indicate advanced marksmanship skills.

One constraint of the subject lying in the prone position was that not all of the markers were visible on the front section of the body. This was because the body position blocked the camera view of the markers. All of the markers underneath the body were reconstructed manually with virtual points to be uploaded into Santos. (Virtual points are discussed in detail later.)

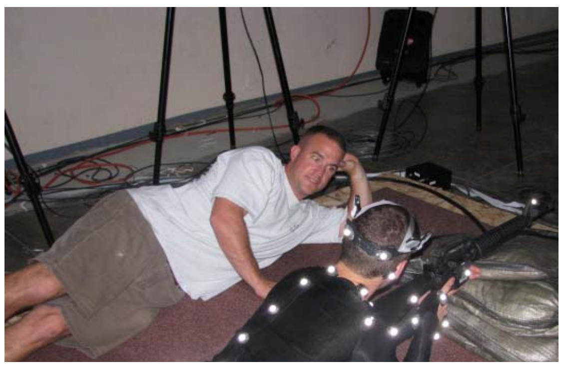

Figure 14. Experimenter Observing Subject.

Each subject received only 18 simulated rounds to zero their weapon. Zeroing a weapon requires the shooter to place the weapon in correct line of sight, point of aim, centerline to the bore, and make any sight adjustments to steady the weapon for correct bullet trajectory and range. For the M16A2, the shooter must battle sight zero the weapon by firing a certain number of shots within the 4-centimeter circle. Bullets that break the line of the 4-centimeter circle will be used in evaluating the shooter's performance. For the EST 2000 the only requirement is to maintain a tight shot group by firing each round with a consistent sight picture. The simulator will then move the "strike" of the round onto the target based on accomplishing the task of firing the three shots in the 4-centimeter circle.

If subjects in this study did not zero their weapon, they were disqualified from the experiment and invited to exit the experiment. The subject was asked to assume the T-Pose before and after 2 iterations of grouping or zeroing. The subject would also assume a T-Pose before and after shooting forty rounds on the simulated qualification pop-up range. Once the subject had completed the firing sequence the marker set was removed. As a final confirmation the subject's data was reviewed to ensure it was filled out correctly on the questionnaire.

5. Subject Motion Capture Calibration

The subject was then escorted to the EST 2000 simulator with the motion capture system in a 360 degree pattern of coverage angle. Subjects then assumed the T-pose, shown in Figure15. To allow the cameras to recognize the skeleton of the individual subject and pick-up the subject's 3D position in space. The next requirement of the subject was to run through a series of body movements better known as "Monkey See, Monkey Do"

Figure 15. T-pose Front Marker Protocol.

The "Monkey See, Monkey Do" process was one that ensured all markers were visible and that all joint angles were showing movement. This process allows the cameras to quickly and efficiently translate all of the subject's joint angles and stores them in a single database, which allows translation of their posture into the Santos

program at a later date. If the T-pose (Shown in Figure 10) and the "Monkey See, Monkey Do" were not conducted the individuals joint angles could never be measured, studied in detail or translated into Santos.

The continuation of the "Monkey see, Monkey do" process (Shown in Figure 16) is a series of movements that start off with the T-pose and ends with the T-pose. The movements are as follows:

-T-Pose (hold for three seconds)
-Bend at the wrists
-Bend at the elbows
-Bend your head
-Bend at the waist
-Bend your knees
-Rotate you wrists
-Rotate your arms
-Rotate your head
-Rotate your waist
-Rotate your knees
-Pick one foot off the ground and rotate your ankles
-T-Pose (hold for three seconds)

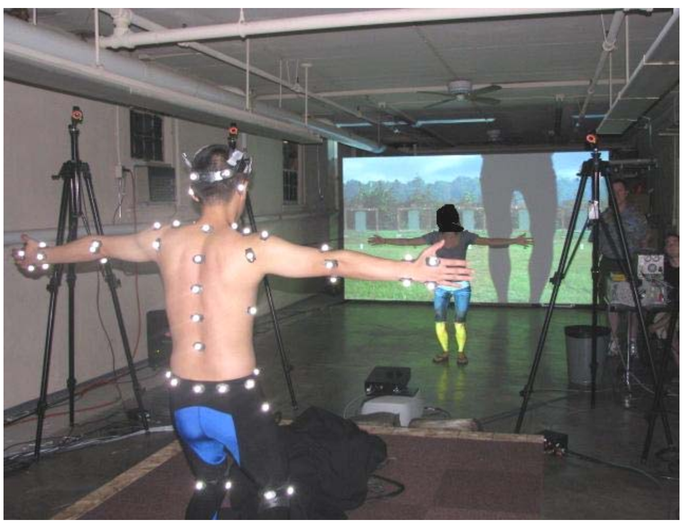

Figure 16. Monkey See, Monkey Do.

Once the cameras were fully calibrated, the subject would then be able to respond to the same movement commands from an EST 2000 operator. The EST 2000 operator gives commands in an identical manner to those given on the live fire range. This ensures that later if this study is conducted at a life fire range that the same process will be used for both. The commands were as follows:

-Firer take a good supported prone position and check to make sure your weapon is on safe.

-Firer ready

-Firer lock and load your magazine and prepare to perform grouping

-Switch your selector lever from safe to semi and fire when ready.

-Firer you have now grouped (when satisfied)

-Firer you will now zero your weapon

-Firer take a good supported prone position and check to make sure your weapon is on safe.

-Firer ready

-Firer lock and load your magazine and prepare to perform your zero

-Switch your selector lever from safe to semi and fire when ready.

-Firer you have successfully zeroed your weapon (when satisfied)

-Firer take a good supported prone position and check to make sure your weapon is on safe.

-Firer ready

-Firer lock and load your magazine and prepare to fire

-Switch your selector lever from safe to semi and watch your lane (this is the pop-up range)

6. Data Collection on EST

The EST 2000 screen allowed the researchers to view most of the subjects' characteristics as they fired on the EST 2000. Data was collected on all seventeen subjects on the EST 2000. The analysis that the researchers conducted was subjective based off of a combined total of thirty-two years of Army Marksmanship experience. The video screen displays point of aim and point of impact, weapon cant, breathing, butt stock pressure, and trigger pull. The experimenter measured the consistent aiming point

by lying on the ground beside each subject. The tip of the nose was observed to determine if the subject placed their nose consistently in relationship to the charging handle during every shot fired. If the subjects never moved they were categorically scored “expert”, if they moved small amounts they were categorically marked “good”, if the movement of the nose was clearly visible they were categorically scored “average”, and if the placement of the nose changed every time they fired they were scored “poor”.

When measuring the point of aim, the researchers were able to observe the screen of the EST 2000 and see how far off the simulated round hit from the intended target. This provided a categorical score for each subject as expert, good, average, poor. The trigger pull could also be measured by observing if the subject “jerked” the trigger or slowly “squeezed” the trigger.

The EST 2000 measures butt stock pressure on a 1-100% scale. If the subject consistently measured between 90-100, they were categorically scored “expert”, If the subject consistently measured between 80-89, they were categorically scored “good”, If the subject consistently measured between 70-79, they were categorically scored “average”, If the subject consistently measured below 70, they were categorically scored “poor”.

Weapon cant was measured in the EST 2000 by the degree of turn around the center axis of the weapon maintains while the subject fired. The specific cant angles at time of fire are shown on the screen and were written down by the researchers. The degrees are measured for both left and right cant angles. A negative 1.3 degrees was scored the same as a positive 1.3 degrees of cant. If the subject consistently measured between 0-2 degrees they were categorically scored “expert”; consistently measured between 2.1-3 degrees they were categorically scored “good”; consistently measured between 3.1-4 degrees they were categorically scored “average”; consistently measured over 4 degrees they were categorically scored “poor”.

H. POST PROCESSING OF MOTION CAPTURE DATA

The actual processing of the motion capture data began on 21 August 2008, and continued through 25 August 2008. An explanation is needed to fully appreciate the

detail and time that it took to render each of the selected subjects. Only four subjects were rendered into Santos, because of time and resource constraints. To render the skeletal figure for four subjects required over 48 hours of analysis. The consultants from UOI were instrumental in providing subject matter expertise while rendering the captured data.

The four subjects chosen for motion capture translation (Figure 17) are listed below:

- Subject #1 represented as our expert shooter firing 40 out of 40
- Subject #7 who shot 31 out of 40 and was a very experienced shooter as a midpoint to our data
- Subject #14 was our worst shooter and could not even group or zero his weapon
- These four subjects were selected from the pool of 17 for the following reasons:
    - Each of the subjects represented different levels of skill.
    - Limited time for post data processing required the selections of specific individuals subjects to attempt to distinguish profiles of those most different.
    - Self feedback the subject and observations from the researchers indicated that the subjects chosen were representative of training levels of new soldiers.
    - Subject 10 was a planned choice in an attempt to illustrate possible training effect that could result in properly conducted after action reviews of subject post experiment.

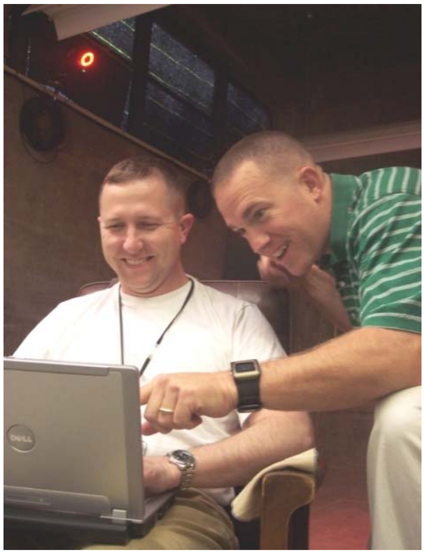

Figure 17. Authors Selecting Subjects.

Subject #10 watched the first 9 subjects complete their testing listening to all feedback given after the subjects completed the experiment. The intent of allowing subject ten to observe the prior subjects during their shooting sessions was to investigate the effect of training on the subject 10. This subject shot 37 out of 40, but was very experienced shooter prior to the experiment so it is not possible to equate expert marksmanship to training effect. Subject 10 did state that watching other subjects fire the weapon before his firing iteration was very helpful. The subject commented that the ability to hear the feedback provided to other subjects after they had completed their firing sequence increased his knowledge base of how to properly fire the M-16A2 rifle.

1. Labeling

As seen in Figure 18, the marker protocol used for data labeling and reconstruction into a 3D image according to the Santos model; some adjustments were required to build the protocol because of the additional markers required to allow the calculation of the joint centers. Each virtual marker required a label that would identify it according to its position on the body and its sequence in the marker protocol. This process can take as much as 8 hours per subject depending on the visibility of the markers and the conversion process. Figure 19 shows the raw data as seen on the motion capture software:

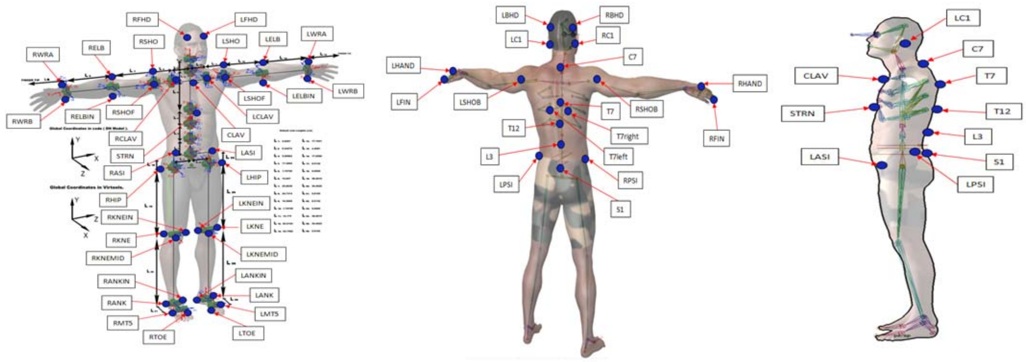

Figure 18. Santos Protocol.

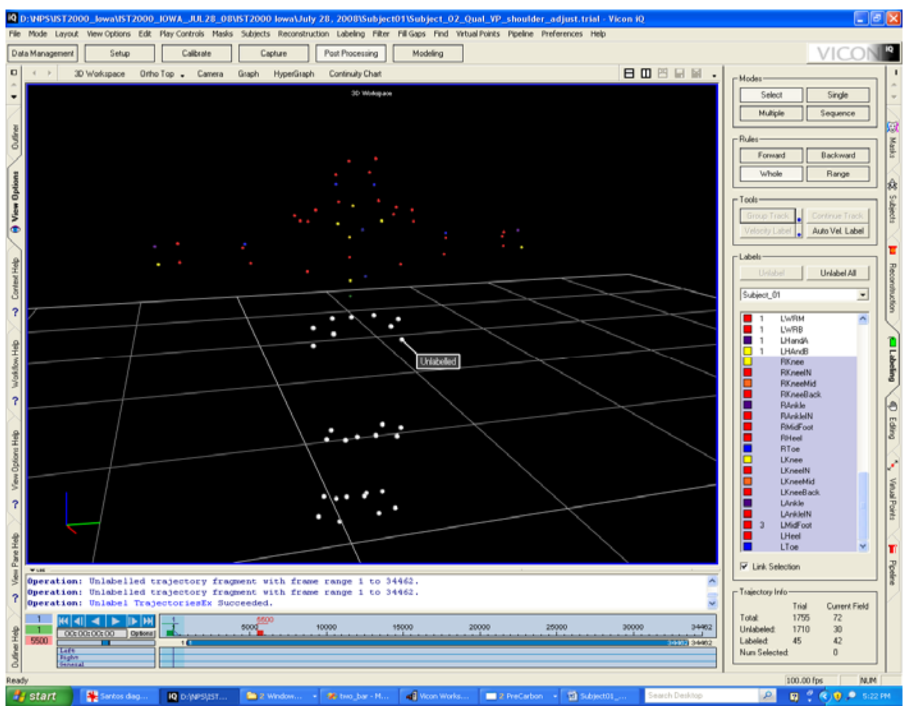

Figure 19. Labeling of RAW Data Points.

2. Editing

In the case of occlusions, the data is edited to fill in the missing marker trajectory. If the occlusion is brief, a spline tool can be used to fill in the gap. A spline of allows the person doing the post processing of data to find a point either before or after the occlusion of the point and add it back to the current frame; this “adding” back of a virtual

point was done on many occasions. Figure 20 shows the process used to add virtual markers into the captured motion for longer gaps, the marker may be associated to other markers located on the same rigid body. For example, markers on the knee may be associated with a different knee marker to allow joint calculations. A Butterworth filter is used to smooth the data and reduce marker jumping. A high cut-off frequency was used here to remove jumping and preserve the jolting motion caused by firing the weapon. This process takes from 2-4 hours.

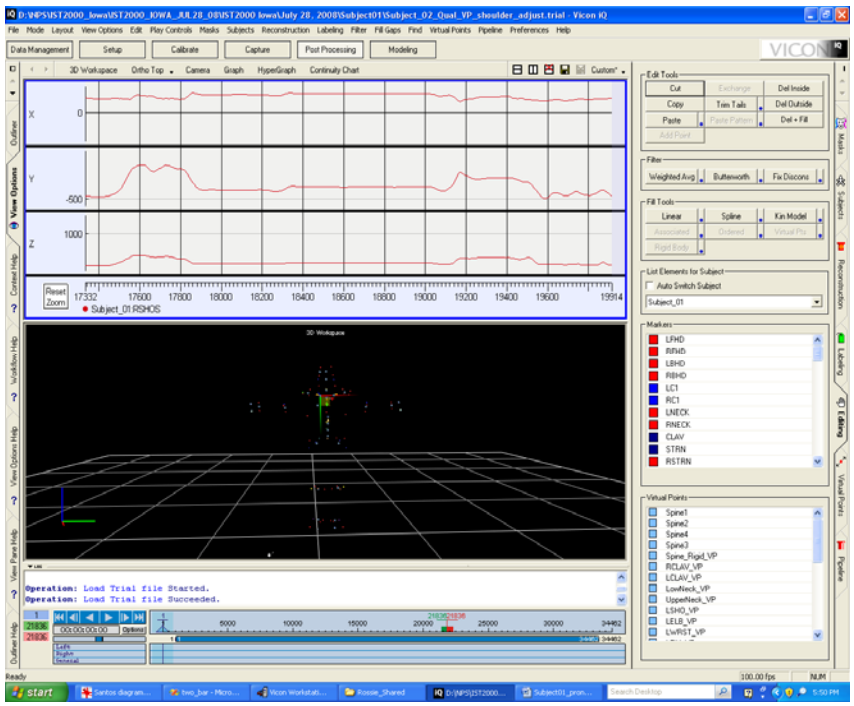

Figure 20. Editing of Data Points.

3. Virtual Points

Virtual points are added to track the motion of body parts that were not visible during the motion capture. As show in Figure 21/22 the added points are needed to provide references to perform the joint center calculation. The added points are calculated based on a known marker position from an earlier or later frame of the recorded data. This allowed the building of a useful model when the subject was in a

position that prevented the capturing of markers obstructed from the cameras view. Figure 23 shows a close up of the subject in the prone position once the processing was completed. This process takes from 1-5 hours.

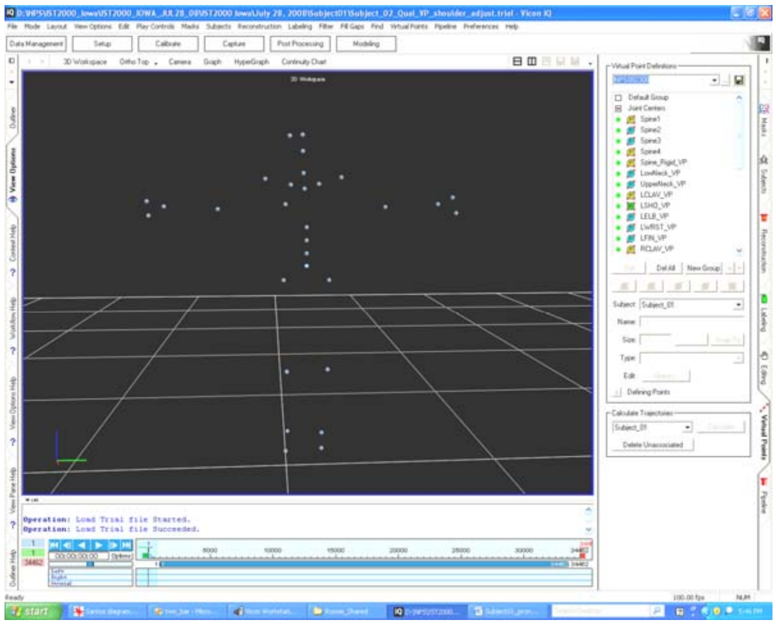

Figure 21. Virtual Points Placed to Allow Joint Angle Determination.

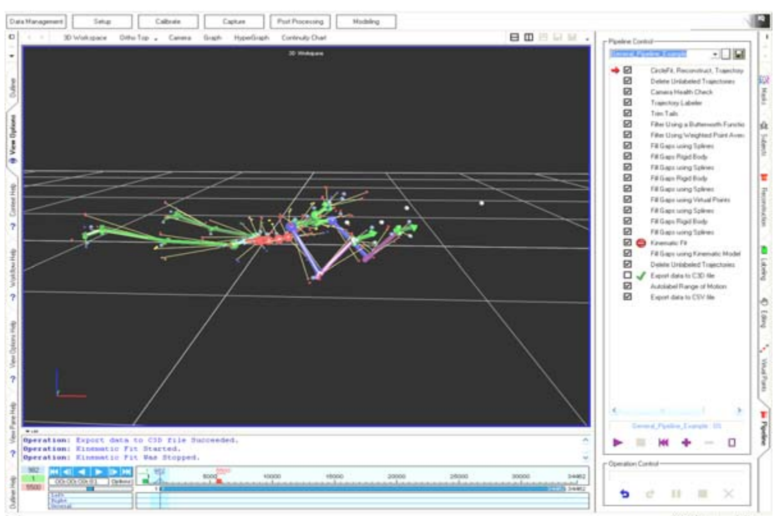

Figure 22. Joint Angles Processed – Required Use of Virtual Points.

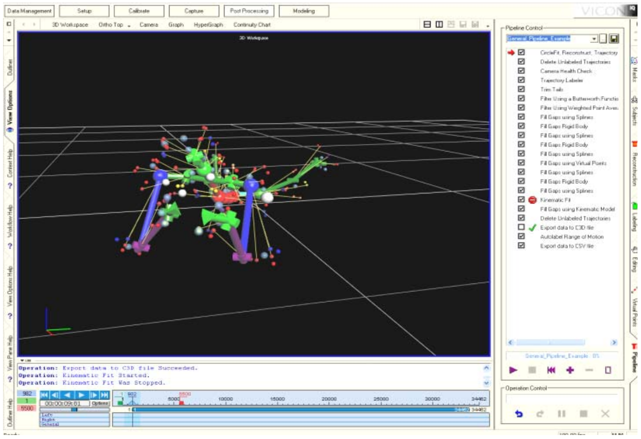

Figure 23. Close Up of Completed Vicon Skeleton (VSK), Front Prone.

4. Data Export

The position of the markers and virtual points can be exported directly from Vicon. These files contain the x, y, z coordinates of each markers placement in the 3D space during the experiment. Virtual points and markers allow the user to create a Santos model. It was necessary to distinguish the markers on the weapon and the subject to ensure a proper model was configured.

5. Inverse Kinematics (IK)

The exported point's positions are run through the IK optimization C code to solve for Santos' joint angles; the screen shot of the IK process is shown in Figure 19. The number of points recorded is large; each 30-45 seconds of data collection represents approximately 55,000 frames. The first three sets of three rounds were used to draw upon for analysis to determine posture profiling. Because of the enormous amount of data collect it was not possible to process all the data. Data points common to all subjects were chosen for analysis.

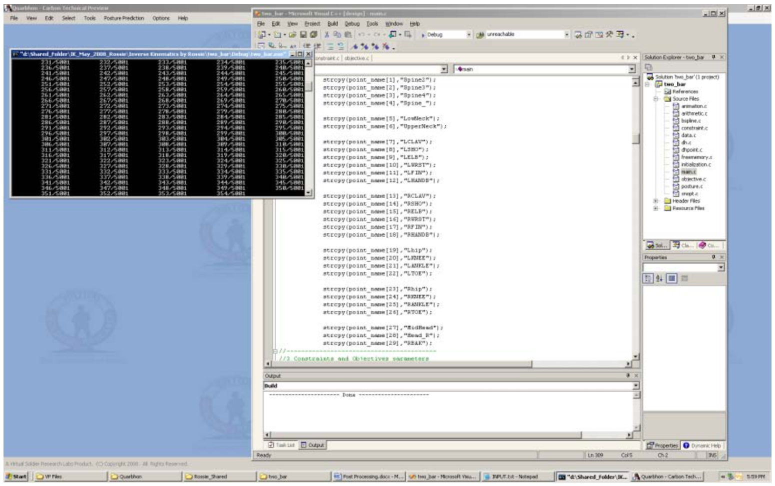

Figure 24. Inverse Kinematics; Processed Frame by Frame.

6. Animation

The IK output joint angles (Show in detail in Figure 25) are animated in Santos using Quarbhon. Santos is scaled to the subject and can be watched as an animated figure from X, Y, or Z axis seen in the next five pictures. Examples of the finished animation are shown in Figures 26-30.

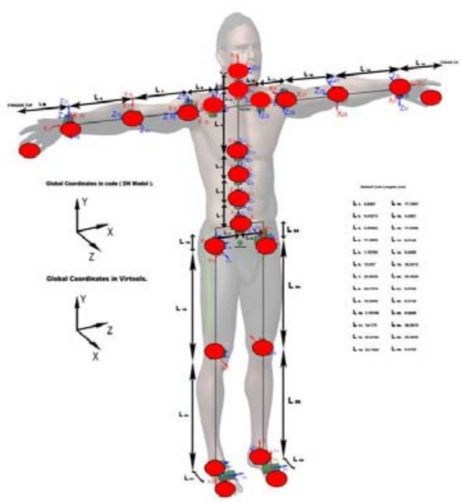

Figure 25. Santos Joint Angels.

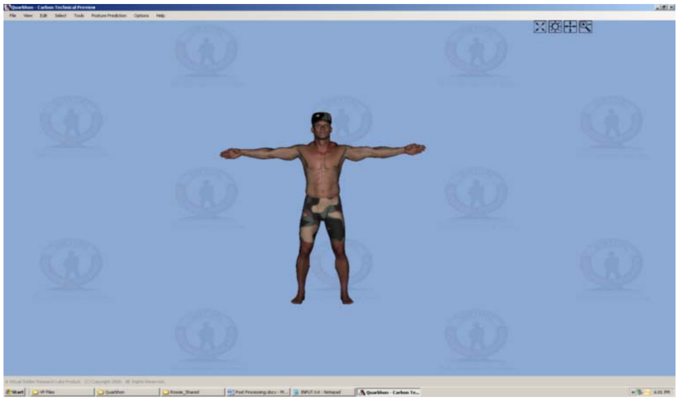

Figure 26. Animated, T-Pose.

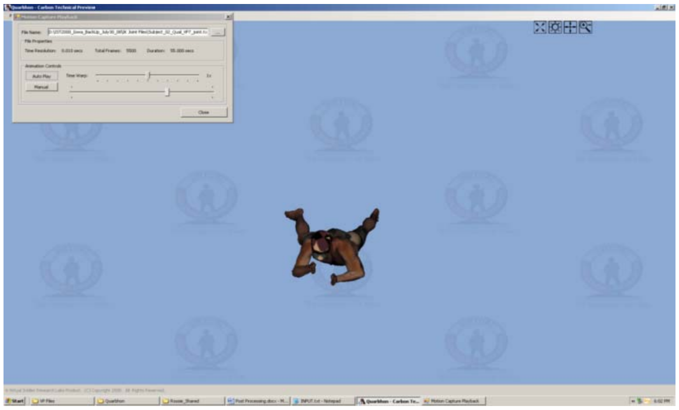

Figure 27. Animated, Prone (X Axis).

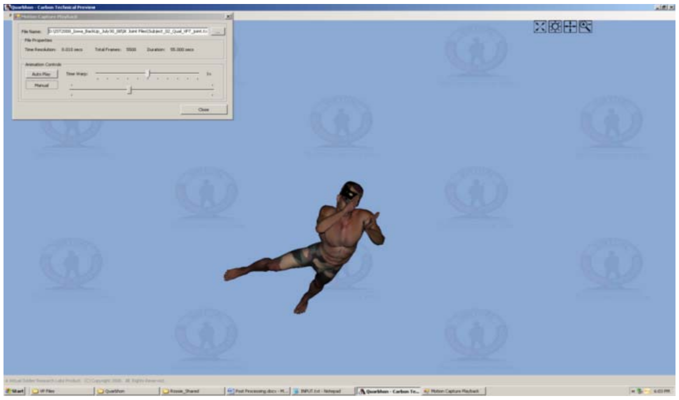

Figure 28. Animated, Prone (Y Axis).

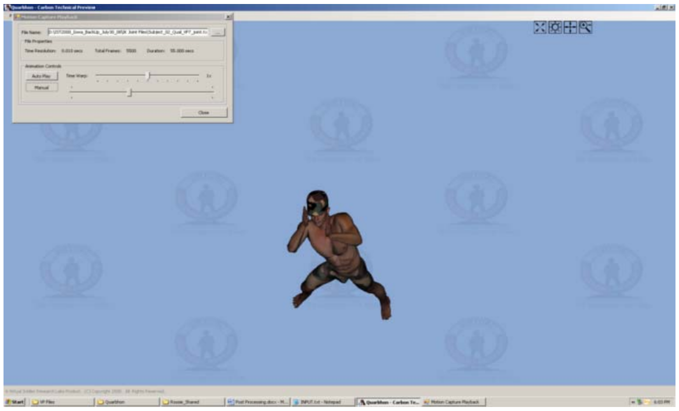

Figure 29. Animated, Prone (Z Axis).

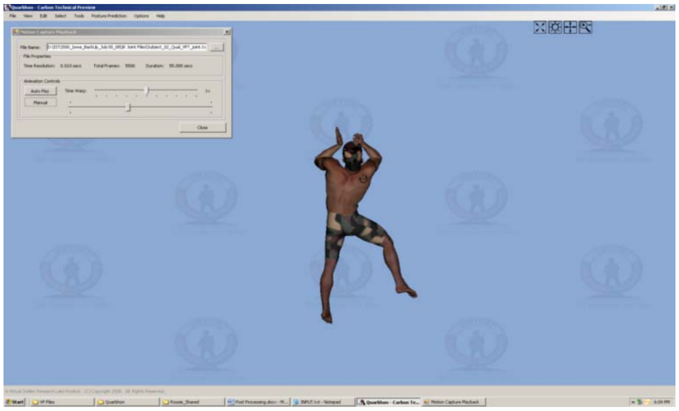

Figure 30. Animated, Overhead View.

VI. RESULTS OF FINAL EXPERIMENT

A. ARE PROFILES CLEARLY VISIBLE AND DISTINGUISHABLE?

The authors asked the question, “Is marksmanship performance clearly visible and distinguishable using motion capture equipment?” After extensive research and data collection, it was possible to determine distinguishable marksmanship profiles using motion capture. Because motion capture allows the measurement of movement at 100 Frames per Second (fps), it was easy to determine that differences existed between marksmen of different skill levels.

As stated earlier, 17 subjects participated in the experiment. The subjects’ responses to non-shooting questions are listed in Appendix 6. This information about the subjects was helpful in selecting a subset of subjects to conduct the analysis. The subjects chosen for the more detailed posture analysis were One, Seven, and Fourteen. Subject Ten was used to examine if a possible training effect would occur by having subject Ten observe the performance and feedback of previous subjects.

The data shows that the performance of a marksman is distinguishable during the firing of the M16A2. Skeletal reconstruction was a very time consuming process taking several hours to render each subject. A decision was made to measure the first three rounds each test subject fired for in-depth analysis. This method was based on picking subjects that fell within three categories of score; Expert, Marksman, Did not Qualify. Subject one scored expert, subject seven scored sharpshooter, and subject fourteen did not qualify. Full motion capture skeletal reconstruction took twelve to thirteen hours to complete for every subject. Given the large amount of time that it took the authors to render each posture into Santos it constrained our ability to build a full motion capture skeletal reconstruction for every subject. All of the motion capture data is available for collaboration for follow on research, but it is the authors’ opinion that analysis of this data will only strengthen the findings reached during this study.

Figures 31-33 show the root mean squares analysis of each shot fired by the subjects. It is possible to show the performance of each shooter when firing each of their three rounds. In Figure 1 subject One is shown in Black and represents the “Expert” marksman; subject Seven is shown in Blue showing the “Medium” marksman; and subject Fourteen is shown in Red representing the “Poor” marksman. Green is used to show a possible “Training Effect” for subject Ten. Figures 31-33 show the movements during 0.2 seconds before and after the shot occur. To provide this data, it was necessary to align these shots into a common representation in time, in order to examine skill differences reflected in movement and stability.

This was done by determining at what point the subjects fired each of the three rounds and then moving their shot to a common place in time. This was accomplished by moving the shot either to the left or right so that they aligned with the other subjects. (Meaning, each of the “first rounds” could have been fired at different times, but each of the shots was only analyzed during the 0.2 seconds before and after they were fired. This procedure allows a comparison to be made. To accomplish this task, the following formula was used: Movement = r.m.s movement is the root mean squared movement of all the joint center locations from

ti to ti+1 $\sqrt{(x_{t_i} - x_{t_{i+1}})^2 + (y_{t_i} - y_{t_{i+1}})^2 + (z_{t_i} - z_{t_{i+1}})^2}$

It was important to determine movement based not on the subject’s movement from the established zero X, Y, Z intercept in the 3D camera space. Instead, all movement was compared with the previous location of the marker in relation to its new position; these positions were reordered frame by frame so the movement was measured by one one-hundredth of a second. Very small degrees of movement were recorded using this method allowing a visual depiction of the subject’s performance.

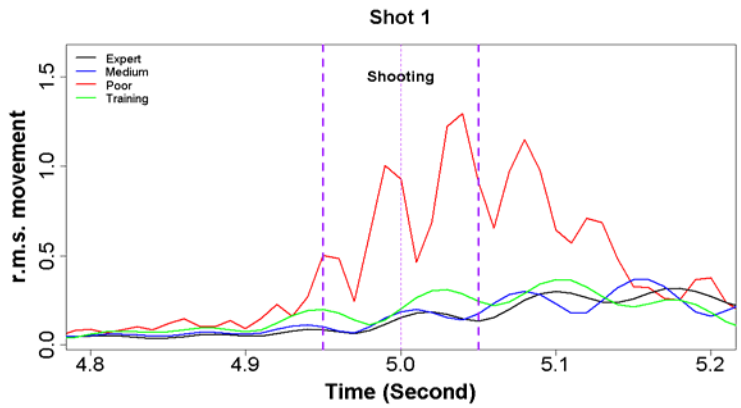

Figure 31. Shot One; Individual Shot Representation.

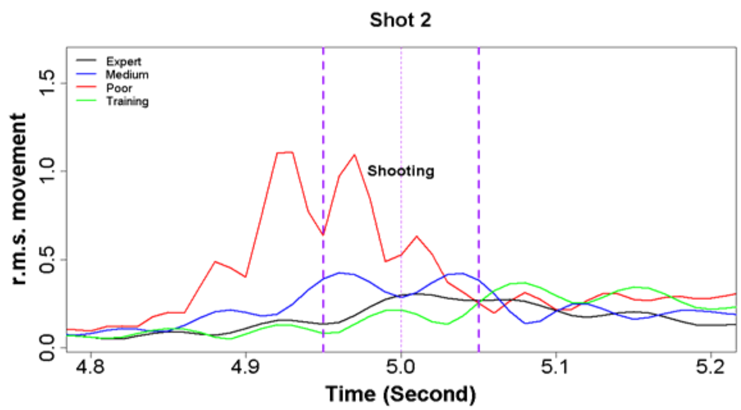

Figure 32. Shot Two; Individual Shot Representation.

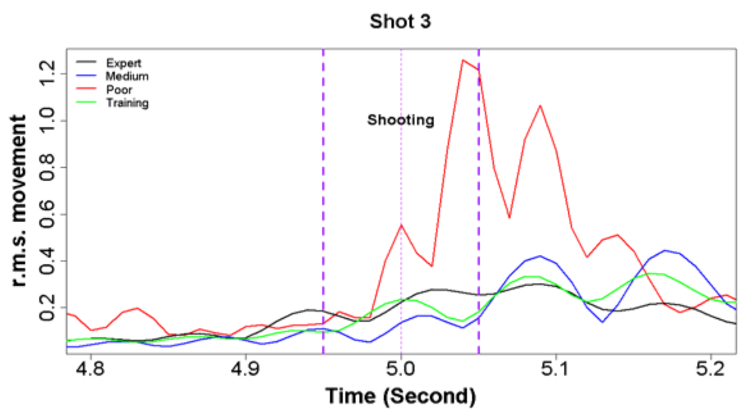

Figure 33. Shot Three; Individual Shot Representation.

Figures 1-3 clearly show that the “Poor” marksman has movement both before and during the firing of their rounds, while the “Medium” marksman shows some movement. The “Expert” marksman tends to have a consistent degree of movement throughout the process. In the study conducted titled *New Directions in Rifle Marksmanship (2006)* the authors Gregory, Chung and Delacruz discuss that when an individual reaches a point of fully conceptualizing a task through repeated practice it is normal for an individual to calm during the performance of a given task. It is also highly likely that a novice will “fidget” around a lot throughout the entire task. (Chung, Delacruz, de Vries, Bewley, & Baker, 2006)

In Figure 34, the same firing sequence is illustrated, but instead of showing the individual scores the averages of all three shots are depicted. It is even more apparent in this figure that the “Novice” marksman has more movement during the firing of each group of three shots. Less apparent when illustrating the average of each shot is the amount of movement each shooter exhibits before and after firing the simulated round.

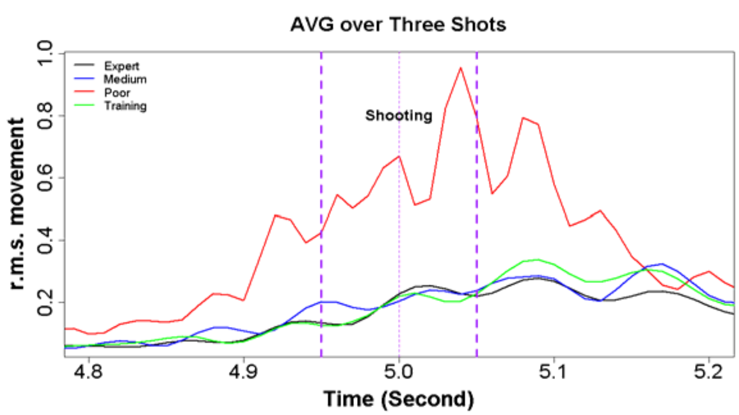

Figure 34. Average of Three Zero Shots.

An extensive period of time was spent developing the design of an experiment to show the use of motion capture depicting the movements of subjects performing the task of zeroing and qualifying an M16A2 during simulation trials. Shown below in Figure 35 is the marker placement for a test subject. Because of the masking of points, it was necessary to add additional markers at key points to the subject so that during post

processing it would be possible to more easily insert missing virtual points. It was through the use of the additional marker set that measurement of the movements of the entire body was possible.

Figure 35. Marker Placement on Male Subject.

Transfer of the virtual points to motion capture was a critical step in proving that profiles could be interpreted. Using motion capture to show the subject firing would show the observer a moving replication of the subject while firing the M16A2. Figure 36 shows a subject using translated data compiled in the Vicon Motion Capture software. It is this translation that is then exported to replicate a useful human approximation, which could serve as a potential augmentation for a virtual marksmanship trainer.

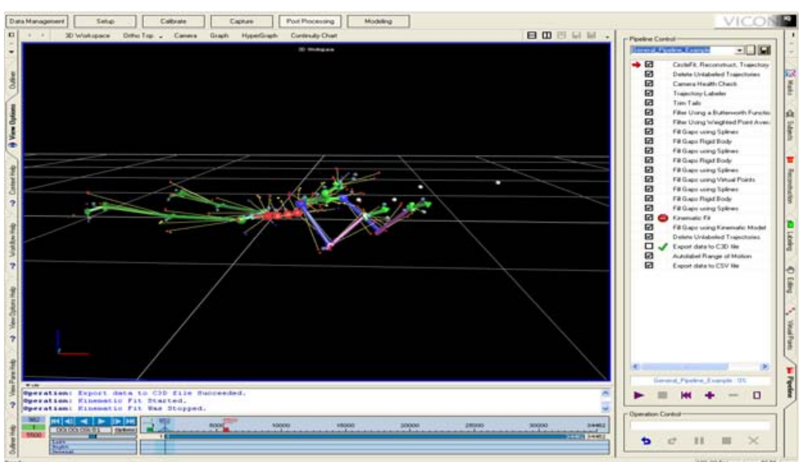

Figure 36. Marker Data Transformed Using Vicon.

The EST 2000 was used to provide an independent confirmation that the data captured using the marker protocol was related to how the subject was scored while conducting their zero. As seen in Figure 37 the EST 2000 was able to provide feedback of the shooter. As the subject engages the target on the EST 2000 the built in laser tracking system accurately follows the breathing patterns and aiming points of each round fired. The yellow dots represent aiming points before the shooter fires his weapon and the blue dots represent aiming position after the shooter has fired his weapon.

Figure 37. EST 2000 Shooter Feedback.

B. CAN ONE BE AN EXPERT MARKSMAN WITHOUT HAVING ALL FIVE CHARACTERISTICS OF FUNDAMENTAL MARKSMANSHIP SKILL?

The second question proposed in this thesis is, “Can one be an expert marksman without having all five characteristics of fundamental marksmanship skill?” The null hypothesis of the experiment is that none of the characteristics of marksmanship has an impact on a subject’s ability to perform as an expert marksman. When conducting a one way ANOVA comparing the subject’s score with trigger pull, breathing, aiming point,

butt stock pressure, and weapon cant it was determined that no statistical evidence was present to support the need of the characteristics of marksmanship. The results of these tests are shown below.

First a determination on which variable would best represent the intended outcome when conducting marksmanship training was selected. Qualification score was the basis for the analysis as an indication of skill level for subjects. The data of all 17 subjects was used to determine if the five fundamentals of marksmanship impacted shooting performance.

The process of data comparison required placing the raw data into a format that was conducive for analysis. SPSS, JMP and Microsoft Excel were used to conduct the analysis of the data, but for final analysis SPSS was used to illustrate the findings for this thesis. By using the qualification score as the Y variable (dependent variable) and the X variable (independent variables being breathing, trigger pull, weapon cant, aiming point and butt stock pressure, it was then possible to rate the subject's performance as categorical data; a score of 36 to 40 representing expert marksmanship for the purposes of this thesis. A regression analysis was performed using the qualification scores as the dependent (y) variable.

All characteristics were analyzed to determine if any played a significant role in the ability of the subject to score well in a simulated M16A2 qualification scenario using the EST 2000. Information extracted from the qualification scenario allowed a subjective analysis of each characteristic to determine if there was any one characteristic that plays a "more" important role in the subject's ability to engage a target. Box plots are used to show the results of the categorical information of the five characteristics using a multiple regression analysis.

Each of the five characteristics was analyzed using the following conditions. Only the data collected from weapons tilt was considered as objective non-categorical data. Each of the four remaining characteristics was assessed using subjective ratings conducted by the authors. Their combined 32 years of military service and their experience using small arms allowed for the subjective analysis. The method of placing

the subject's scores into categories considered the combination of motion capture analysis, EST 2000 feedback, and recorded information taken by the researchers during the EST 2000 experiment.

The first characteristic analyzed was "Trigger Pull." As shown in Figure 38, the subject's score appeared to be dependent on their ability to pull the trigger smoothly without jerking laterally. By using box plots, it is possible to show that the four subjects listed in Table 1 have a high degree of trigger control which by inference would demonstrate the need exists to have a smooth consistent trigger pull while firing a weapon. Subjects who scored lowest on qualification are also those who have the worst "Trigger Pull."

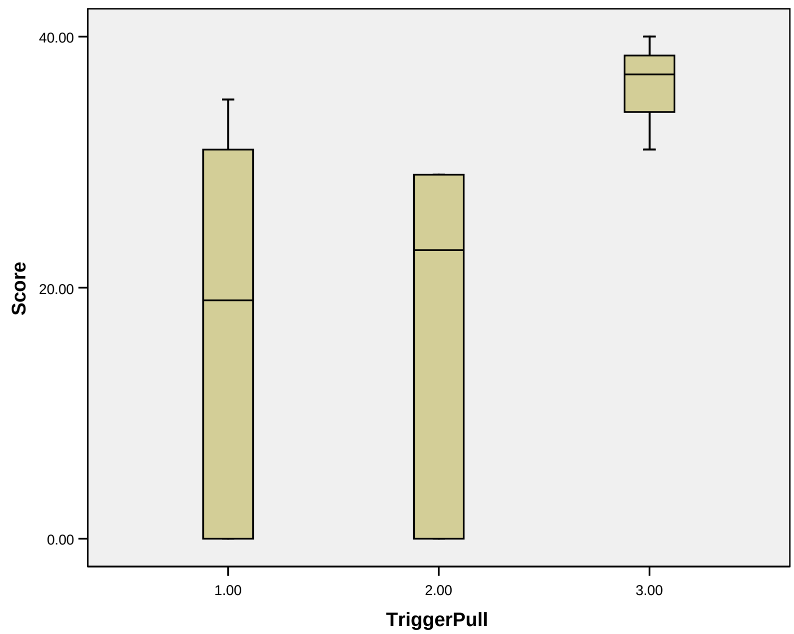

Figure 38. Trigger Pull Box Plot.

		Cases					
		Valid		Missing		Total	
	TriggerPull	N	Percent	N	Percent	N	Percent
Score	1.00	8	100.0%	0	.0%	8	100.0%
	2.00	5	100.0%	0	.0%	5	100.0%
	3.00	4	100.0%	0	.0%	4	100.0%

Table 1. Trigger Pull Data.

The second characteristic studied was “Butt Stock Pressure.” Butt Stock Pressure is determined by the subject maintaining a consistent pressure of the weapon’s butt stock into their shoulder joint. Looking at the box plots shown in Figure 39 alone could lead to the impression that Butt Stock Pressure is equal between those who scored high on qualification and those who scored lower. This is not the case; as shown in Table 2 eight of the subjects scored a 4.0 on the Butt Stock Pressure measurement. Lack of consistent Butt Stock Pressure seemed to have little effect on the subject’s qualification score. Understanding this data point would later prove valuable in determining if this characteristic plays a role in expert marksmanship.

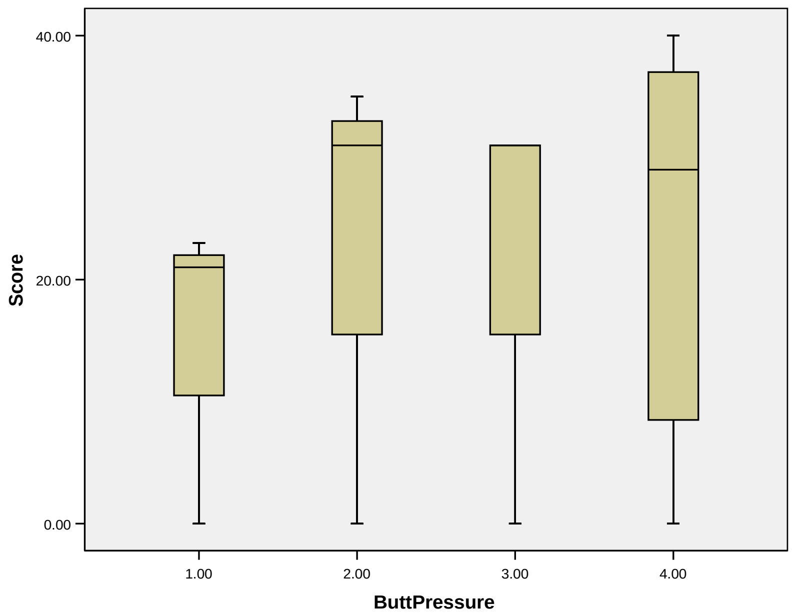

Figure 39. Butt Stock Pressure Box Plot.

		Cases					
		Valid		Missing		Total	
	ButtPressure	N	Percent	N	Percent	N	Percent
Score	1.00	3	100.0%	0	.0%	3	100.0%
	2.00	3	100.0%	0	.0%	3	100.0%
	3.00	3	100.0%	0	.0%	3	100.0%
	4.00	8	100.0%	0	.0%	8	100.0%

Table 2. Butt Stock Pressure Data.

The third characteristic analyzed was “Breathing.” Breathing is one of the hardest of all the characteristics to control. It takes time to learn the art of controlling one’s

breathing in order to become an expert marksman. During an interview conducted at Fort Benning, GA SSG Joseph Peeples, a U.S. Army Sniper School Instructor, talked at length about the need for a soldier to understand the impact breathing plays on their point of aim. He went on to state that a soldier must understand the body's natural characteristics that are related to breathing are just as important to those shooting. He stated that one must understand that by controlling one's breathing it would allow the slowing of the heart beat and ensures the body has enough oxygen to prevent an impact on eye sight (Peeples, 2008).

As shown in Figure 40 breathing had significant impact on the score of a subject while conducting qualification. The box plot shows that one of the most significant factors to scoring high on qualification was the ability to control one's breathing. The data in Table 3 supports this analysis by showing that four of those subjects who had the highest scores ranked highest in breathing control.

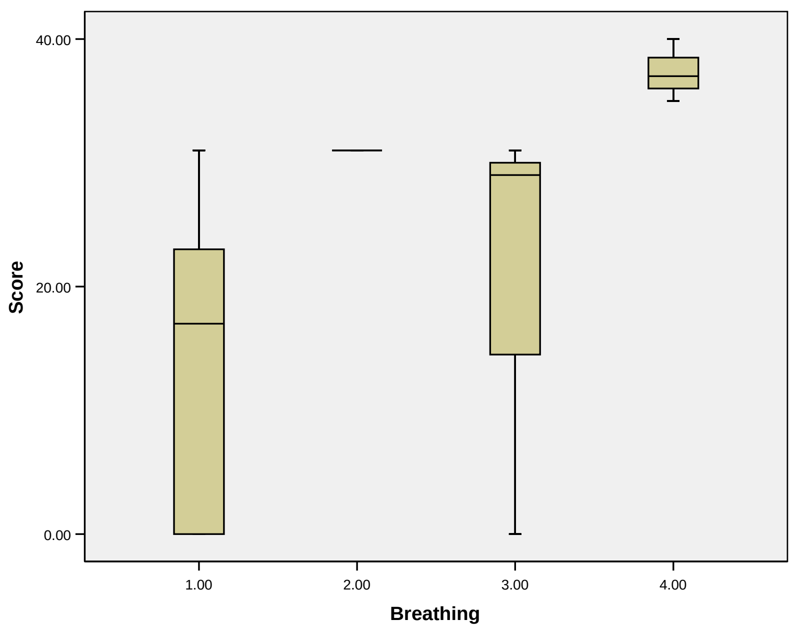

Figure 40. Breathing Box Plot.

	Breathing	Cases					
		Valid		Missing		Total	
		N	Percent	N	Percent	N	Percent
Score	1.00	9	100.0%	0	.0%	9	100.0%
	2.00	1	100.0%	0	.0%	1	100.0%
	3.00	3	100.0%	0	.0%	3	100.0%
	4.00	4	100.0%	0	.0%	4	100.0%

Table 3. Breathing Data.

The fourth characteristic analyzed was “Aiming Point.” Aiming point was determined by using the EST 2000 data to determine if the subject was consistent in maintaining their point of aim. As seen in Figure 41, the box plots show that one’s ability to maintain a steady aim increases the likelihood of scoring higher during qualification. The data presented in Table 4 shows a relatively even distribution among subjects. All analysis of the data included all outliers.

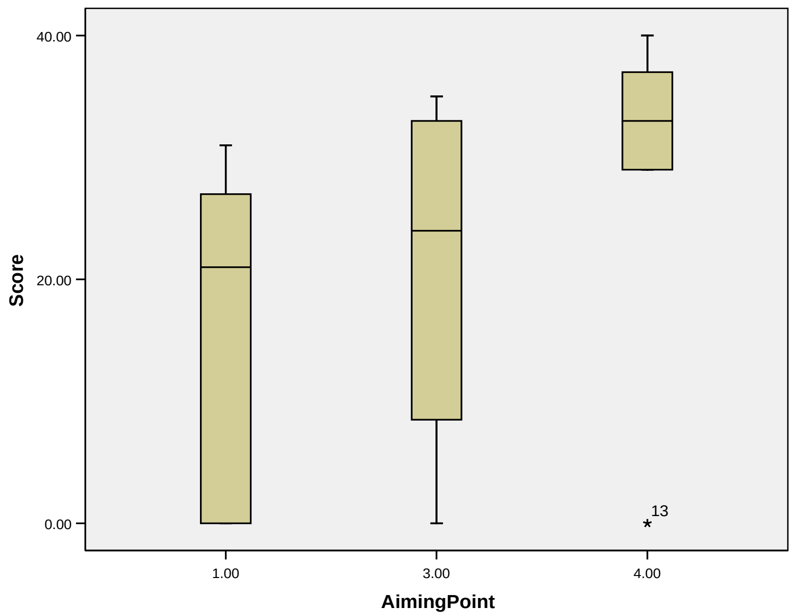

Figure 41. Aiming Point Box Plot.

		Cases					
		Valid		Missing		Total	
	AimingPoint	N	Percent	N	Percent	N	Percent
Score	1.00	7	100.0%	0	.0%	7	100.0%
	3.00	4	100.0%	0	.0%	4	100.0%
	4.00	6	100.0%	0	.0%	6	100.0%

Table 4. Aiming Point Data.

The last characteristic analyzed was "Weapon Tilt." Weapon tilt data was the only objective non-categorical data used. When the data is placed in a scatter plot it is apparent that there seemed to be no grouping of scores based on the weapon tilt of the subject during qualification. As shown in Figure 42 the scores are random in relation to weapon tilt. However, there was no significant correlation between weapon tilt and qualification scores.

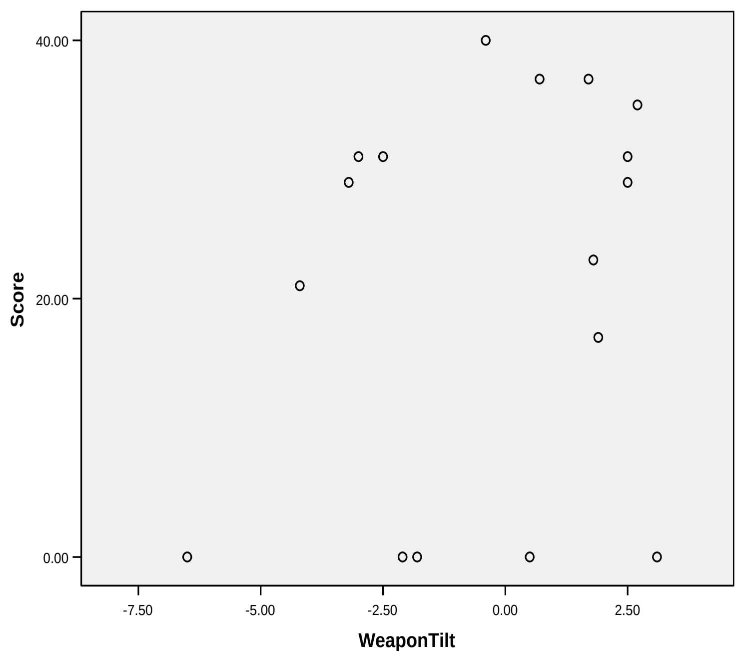

Figure 42. Weapon Tilt Scatter Plot.

		WeaponTilt	Score
WeaponTilt	Pearson Correlation	1	.248
	Sig. (2-tailed)		.336
	N	17	17
Score	Pearson Correlation	.248	1
	Sig. (2-tailed)	.336	
	N	17	17

Table 5. Weapon Tilt Correlation Test.

As shown in Table 5 when weapon tilt is tested using the Pearson two-tailed test no significance was found. This is further shown using a Spearman's test for correlation as show in Table 6.

			WeaponTilt	Score
Spearman's rho	WeaponTilt	Correlation Coefficient	1.000	.161
		Sig. (2-tailed)	.	.536
		N	17	17
	Score	Correlation Coefficient	.161	1.000
		Sig. (2-tailed)	.536	.
		N	17	17

Table 6. Spearman's Test for Weapon Tilt Correlation.

It appeared after this analysis that some characteristics were more significant than others. Regression on all five characteristics was performed in an attempt to test the null hypothesis. This was done in a sequence of test shown in the tables listed below.

1. Analysis of All Five Characteristics of Marksmanship

First the model shown in Table 7 was constructed to provide the conditions for testing. Using all five of the characteristics as predictors the R was over 0.65.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.657[a]	.432	.174	13.86384

a. Predictors: (Constant), AimingPoint, TriggerPull, WeaponTilt, ButtPressure, Breathing

Table 7. Statistical Model including all Five Characteristics.

Next a regression analysis was conducted to determine if any statistical significance was present in the model containing all five characteristics. As shown in Table 8 the results were not significant.

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1606.791	5	321.358	1.672	.222[a]
	Residual	2114.268	11	192.206		
	Total	3721.059	16			

a. Predictors: (Constant), AimingPoint, TriggerPull, WeaponTilt, ButtPressure, Breathing

b. Dependent Variable: Score

Table 8. ANOVA of Model of Five Characteristics.

Since no significance was found when testing this model, the researchers then examined the coefficients using all five characteristics as shown in Table 9. The coefficients provided data on the importance of the characteristics. The second test on this data set was to determine if a correlation existed between "Weapon Tilt" and qualification score. The analysis shown in Table 10 allowed a determination that "Weapon Tilt" showed the least correlation of the five characteristics. More analysis was needed, but at this time "Weapon Tilt" was removed from the model. This interpretation made sense based on the subject matter expertise of the authors. The strike of the round when firing has little to do with the rotation of the weapon using the barrel as the point of rotation in a clockwise or counterclockwise manner.

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	5% Confidence Interval for		Collinearity Statistics	
		B	Std. Error	Beta			ower Bound	Upper Bound	Tolerance	VIF
1	(Constant)	4.661	11.434		.408	.691	-20.505	29.827		
	WeaponTilt	.270	1.398	.051	.193	.851	-2.808	3.347	.752	1.330
	TriggerPull	4.728	6.483	.258	.729	.481	-9.541	18.997	.414	2.418
	ButtPressur	-3.191	4.161	-.251	-.767	.459	-12.349	5.967	.484	2.066
	Breathing	4.440	3.879	.383	1.145	.277	-4.097	12.976	.460	2.173
	AimingPoint	3.288	3.669	.296	.896	.389	-4.788	11.363	.472	2.118

a. Dependent Variable: Score

Table 9. Coefficient Analysis of the Five Characteristics.

Model			AimingPoint	TriggerPull	WeaponTilt	ButtPressure	Breathing
1	Correlations	AimingPoint	1.000	.380	-.320	-.555	-.439
		TriggerPull	.380	1.000	-.185	-.479	-.662
		WeaponTilt	-.320	-.185	1.000	-.050	.096
		ButtPressure	-.555	-.479	-.050	1.000	.252
		Breathing	-.439	-.662	.096	.252	1.000
	Covariances	AimingPoint	13.463	9.046	-1.642	-8.467	-6.245
		TriggerPull	9.046	42.030	-1.675	-12.929	-16.652
		WeaponTilt	-1.642	-1.675	1.955	-.290	.522
		ButtPressure	-8.467	-12.929	-.290	17.313	4.064
		Breathing	-6.245	-16.652	.522	4.064	15.043

a. Dependent Variable: Score

Table 10. Correlation Testing of the Five Characteristics.

2. Analysis of the Four Remaining Characteristics of Marksmanship

Another analysis was conducted with the exclusion of “Weapon Tilt.” By constructing a model using only four independent variables more precision was expected. Shown in Table 11 there is little change in the tested values.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.656[a]	.430	.240	13.29604

a. Predictors: (Constant), AimingPoint, TriggerPull, ButtPressure, Breathing

Table 11. Statistical Model of Four Characteristics.

The following tables show the analysis that excluding “Weapon Tilt” from the model testing the null hypothesis.

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1599.644	4	399.911	2.262	.123[a]
	Residual	2121.415	12	176.785		
	Total	3721.059	16			

a. Predictors: (Constant), AimingPoint, TriggerPull, ButtPressure, Breathing

b. Dependent Variable: Score

Table 12. ANOVA of Model of Four Characteristics.

Shown in Table 12 is the significance of the model increased by .099 by excluding “Weapon Tilt”.

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.	95% Confidence Interval for B Lower Bound	95% Confidence Interval for B Upper Bound	Collinearity Statistics Tolerance	Collinearity Statistics VIF
1	(Constant)	3.615	9.654		.374	.715	-17.420	24.650		
	TriggerPull	4.959	6.111	.270	.812	.433	-8.355	18.273	.428	2.336
	ButtPressure	-3.151	3.985	-.247	-.791	.444	-11.835	5.532	.485	2.061
	Breathing	4.368	3.702	.377	1.180	.261	-3.699	12.435	.464	2.153
	AimingPoint	3.514	3.334	.317	1.054	.313	-3.750	10.778	.526	1.901

a. Dependent Variable: Score

Table 13. Coefficient Analysis of Four Characteristics.

As shown in Table 13, “Butt Stock Pressure” is slightly less significant than “Trigger Pull.” The next step would be to test for correlation to see if it is was necessary to eliminate an additional characteristic.

Model			AimingPoint	TriggerPull	ButtPressure	Breathing
1	Correlations	AimingPoint	1.000	.345	-.603	-.433
		TriggerPull	.345	1.000	-.498	-.659
		ButtPressure	-.603	-.498	1.000	.258
		Breathing	-.433	-.659	.258	1.000
	Covariances	AimingPoint	11.114	7.027	-8.012	-5.341
		TriggerPull	7.027	37.339	-12.120	-14.904
		ButtPressure	-8.012	-12.120	15.884	3.809
		Breathing	-5.341	-14.904	3.809	13.708

a. Dependent Variable: Score

Table 14. Correlation Testing of Four Characteristics.

Using the results of the correlations it was determined that “Butt Stock Pressure” showed the least correlation of the remaining characteristics. The subjective data suggested that the remaining characteristics warranted a separate analysis.

3. Analysis of the Three Remaining Characteristics of Marksmanship

Analysis of the three remaining characteristics was conducted in the same manner as the previous two tests. The first step was to construct the model for analysis. This model is shown in Table 15. The model shows only slight improvement over the four

and five characteristic models, but improvement does exist. It was still not possible to reject the null hypothesis with the data used for this test.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.633[a]	.400	.262	13.10298

a. Predictors: (Constant), AimingPoint, TriggerPull, Breathing

Table 15. Statistical Model of the Remaining Three Characteristics.

An ANOVA test on the remaining characteristics was conducted. The results of this test are shown in Table 16.

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1489.114	3	496.371	2.891	.076[a]
	Residual	2231.945	13	171.688		
	Total	3721.059	16			

a. Predictors: (Constant), AimingPoint, TriggerPull, Breathing

b. Dependent Variable: Score

Table 16. ANOVA of Model Three Characteristics.

The new model increased significance another .047 over the previous model, and .146 over the first model using all five characteristics. The next step was to analyze the coefficients of the remaining characteristics. Since the results were over 0.05 we failed to reject our null hypothesis. The results of this analysis are shown in Table 17.

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	5% Confidence Interval for		Collinearity Statistics	
		B	Std. Error	Beta			Lower Bound	Upper Bound	Tolerance	VIF
1	(Constant)	1.010	8.943		.113	.912	-18.310	20.331		
	TriggerPull	2.554	5.223	.139	.489	.633	-8.729	13.838	.569	1.757
	Breathing	5.123	3.525	.443	1.453	.170	-2.492	12.739	.498	2.009
	AimingPoin	1.924	2.621	.173	.734	.476	-3.738	7.587	.827	1.210

a. Dependent Variable: Score

Table 17. Coefficient Analysis of Three Characteristics.

The significance of the coefficients was still not statistically significant. The next test was to determine if there was correlation with the remaining three characteristics.

Model			AimingPoint	TriggerPull	Breathing
1	Correlations	AimingPoint	1.000	.065	-.359
		TriggerPull	.065	1.000	-.633
		Breathing	-.359	-.633	1.000
	Covariances	AimingPoint	6.869	.887	-3.321
		TriggerPull	.887	27.281	-11.652
		Breathing	-3.321	-11.652	12.426

a. Dependent Variable: Score

Table 18. Correlation Testing of Three Characteristics.

4. Composite Score Using Three Characteristics

A decision was made to conduct analysis using a composite score of the three remaining characteristics of marksmanship. Although this step was a departure from the null hypothesis originally presented, a series of tests would be conducted using a composite score analysis. The accepted practice of marksmanship stated all the characteristics are needed to perform as an expert. (FM 3-22.9 Rifle Marksmanship, 2008) Since no one of the characteristics is as important without the performance of the others the composite score could possibly lead to a better understanding of the need of the characteristics of marksmanship to be taken as a collective skill.

The final step in determining if the three remaining characteristics provided a statistically significant accounting for expert marksmanship was to conduct an analysis using the same process used previously on the characteristics. A composite score was derived using the same matrix, but instead each of the characteristics of Aim Point, Trigger Pull, and Breathing were added together and the mean taken for this analysis.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.617[a]	.381	.339	12.39409

a. Predictors: (Constant), composite

Table 19. Composite Score of Three Characteristics.

The results shown in Table 19 were expected because of the reduction of independent variables. An ANOVA test was needed on the data to determine if statistical significance could be achieved using a composite score of the remaining characteristics. It was the researcher's decision to run several different types of data analysis in an effort to show how individual characteristics alone are not as important as combining the characteristics together. This solidifies the principle that marksmanship training is not simply a collection of subtasks.

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1416.856	1	1416.856	9.224	.008[a]
	Residual	2304.202	15	153.613		
	Total	3721.059	16			

a. Predictors: (Constant), composite

b. Dependent Variable: Score

Table 20. ANOVA Model of Composite Total of Three Characteristics.

Table 20 shows the results of the authors' decision to use a composite score to test the data. A significance of .008 was reached. This data shows that the three remaining characteristics, when combined, are critically important to the performance of expert marksmanship. A second test was performed to determine using the categorical data point of "Butt Stock Pressure" included in the mean would affect the significance of the test. These results in Table 21 show that when "Butt Stock Pressure" included all statistical significance is lost in the model.

Score

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	2135.559	9	237.284	1.048	.487
Within Groups	1585.500	7	226.500		
Total	3721.059	16			

Table 21. ANOVA Model of Composite Score of Four Characteristics.

Based on this analysis, the data shows that it is not necessary to have all five characteristics in order to be an expert marksman, but taken individually the characteristics are not meaningful. What this analysis did prove is that the doctrine on marksmanship is sound. All characteristic are needed to some degree to perform the task of expert marksmanship. With the new “red dot” sights used for marksmanship it is the opinion of the authors’ that the three characteristics of “Trigger Pull, Aiming Point, and Breathing” will continue to play a principle role in the development of expert marksman.

C. CAN A VIRTUAL TRAINER DEMONSTRATE CORRECT POSTURE?

The final question asked is, “Could a virtual trainer demonstrate what “Right” looks like by showing correct shooting profiles based on motion capture? It is the opinion of the authors’ that the answer is “Yes.”

Through the use of motion capture, it is possible to capture the posture of an expert marksman. It is also possible to map a subject and then overlay the two models to compare the differences. By doing this the soldier could then “see their actions” while firing the weapon and make corrections.

In Figure 43, the Santos model depicts the possibility of replicating the movements of a soldier in virtual reality. This would then allow the soldier to see what “right” looks like when firing their weapon. The subject’s hands were not marked with the reflective markers; therefore it was impossible to capture the true motion of the individual hand movements. The trigger pull of each subject was determined using the joint angles measured in the Vicon Motion Capture System and by the measurements of the EST 2000 on the screen. It was possible to watch a playback screen on the EST 2000 to then compare the subtle movements in motion capture at the time the subject fires the weapon.

Numerous papers have been written by the VSR team at the UOI. This research is an excellent example of using an already developed simulation that could be utilized to better train soldiers. Santos is a realistic life-like representation of a human; Figure 44

shows the virtual human walking. Because the VSR program was originally an Army sponsored project it can provide a life like representation of the data captured while a soldier fires a weapon and then play it back.

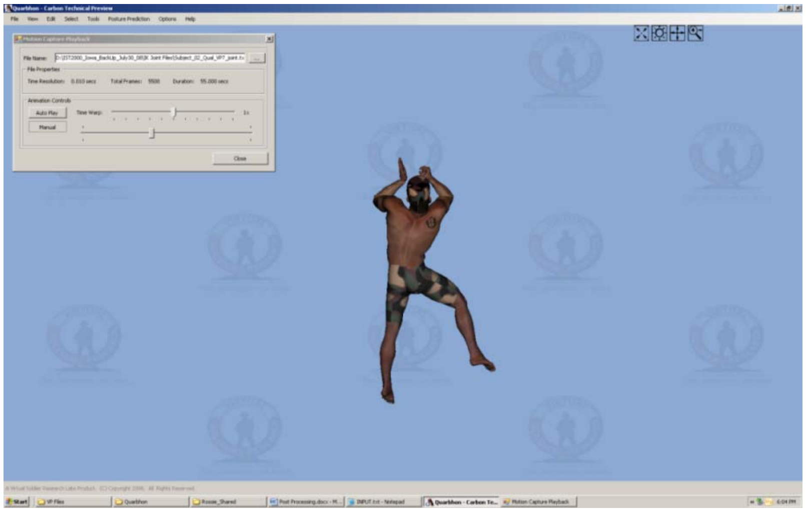

Figure 43. Virtual Posture of Subject One in Prone Position.

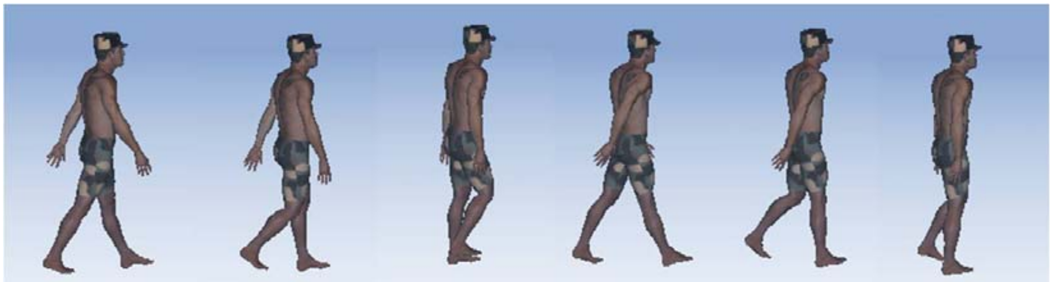

Figure 44. Santos walking.

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VII. CONCLUSIONS AND RECOMMENDATIONS

This thesis concludes with at number of recommendations that would provide an enhanced training capability for rifle marksmanship and increased understanding of the use of motion capture.

A. USE OF POSTURES TO IMPROVE TRAINING

Since performance profiles are identifiable additional research is needed to determine if this capability would provide an enhanced training capability for not only marksmanship skills but any skill that would benefit from repeated performance of a task. The foundation of using motion capture technology to study profiles has been established and is only limited to the user's ability to quickly record and process the data.

Rendering the data to provide real-time feedback is essential to make this process useful during military training and during combat operations. Time was a constrained resource for the researchers as they translated the data from the Vicon motion capture system into the Santos human model. This process took over four days to render four subjects data into the Santos human model and render posture profiles.

The need to explore other motion capture technologies that would more quickly measure the body mechanics of each subject and translate the data into Santos is necessary if the goal is to turly provide instant training feedback. This would then allow for the subject to visually see their posture being represented in real-time. Future research demands for a development and use of faster hardware and software data transfer packages that quickly gives visual feedback to the soldier. To use Santos as a training tool within the Army as a real time trainer calls for a much faster rendering process.

A possible use of Santos as a trainer is to map the soldier using some form of motion cpature to allow the individual's posture while they fire to be calculated againt a set of paramters that are calculated to meet the needs of the individual marksman during shooting. If the soldier is not in the right posture then Santos would have a alert the marksman using a color scheme that would depict where the soldier needs to correcet

their actions. For example, if the trigger finger is blinking red on Santos then the soldier needs to correct the method in which he pulls the trigger. Creating this real time Santos model would allow the soldier to not only envision what right looks like but, correct their posture.

Technology is currently under development at the University of North Carolina and other location that takes 2D video of the subject performing a task, and then creating a 3D image. If this process was fully developed, it would allow the possible use of a hand-held camera to capture the data during training and combat to test process against the actual preformed task.

B. MOTION CAPTURE AND MARKSMANSHIP CHARACTERISTICS STUDIED

The statistical analysis of the performance profiles does not quantitatively suggest that all five characteristics; trigger pull, breathing, consistent aiming point, butt stock pressure, and weapon cant are significant enough in our experiment to justify failing to reject our null hypothesis. The analysis on the one way ANOVAs was subjective categorical data that was derived from viewing the video of the EST 2000 screen as the subject fired, and the researcher's notes as they lay next to the subject during the experiment. The authors consider themselves subject matter experts on rifle marksmanship after a combined total of thirty two years of Army marksmanship training and both researchers consistently firing expert on the Army's qualification range.

Recommendations for future research, explores the possibility of building a virtual avatar of the weapon into the Santos marker protocol software package. The avatar could then represent the weapon in Santos scene standing apart from the subject's marker protocol. Vicon will represent the markers on the actual weapon but, once the researcher's rendered the data points into Santos to compare and measure posture profiles the constant point on the weapon was lost. Once the avatar is built and rendered into the software of the Santos human model one could scientifically compare rigid points on the weapon with body posture and positioning to properly analyze the data as depicted below in Figure 45 showing the current marker protocol and the attempt to place a weapon with markers on it as show in Figure 46.

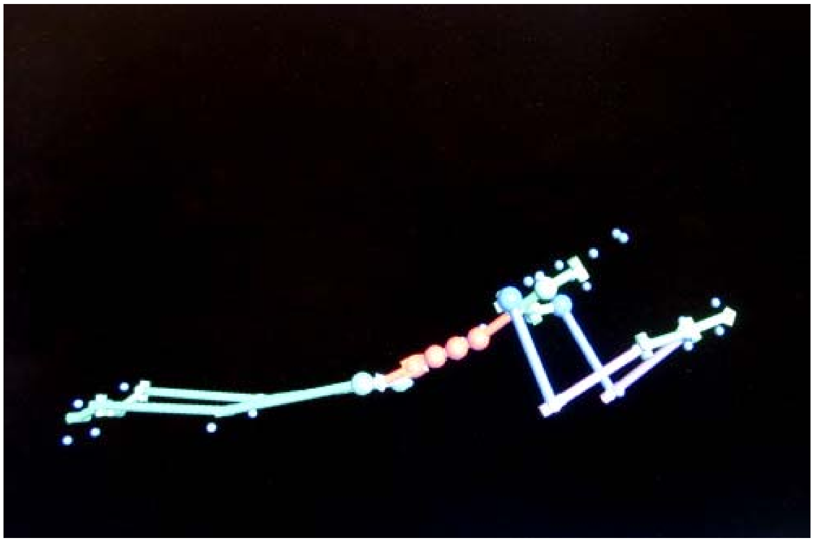

Figure 45. Current Santos Marker Protocol.

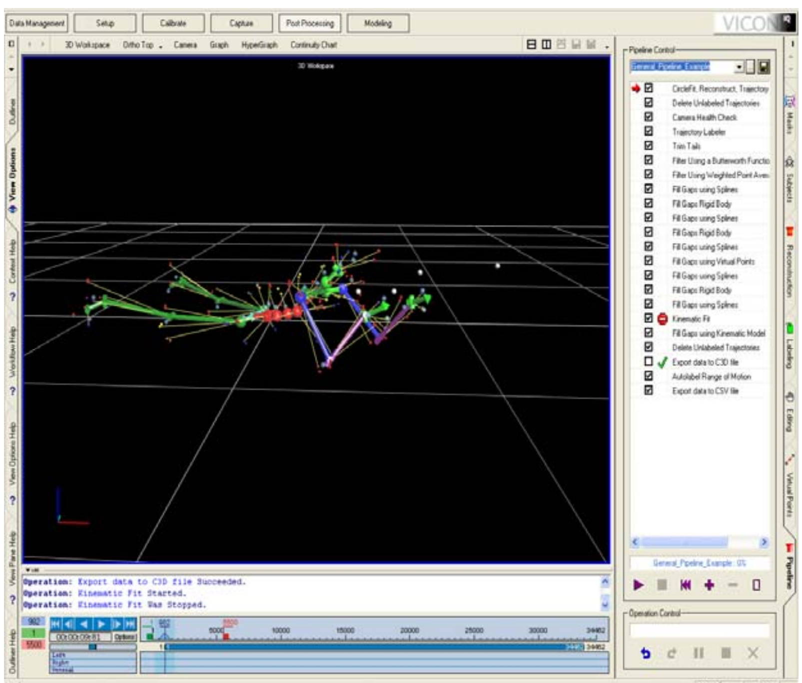

Figure 46. Recommended Santos Marker Protocol.

The constant points on the weapon could then be compared to the marker set on any point on the body to measure individual movements while firing.

C. SAMPLE SIZE AND STATISTICAL SIGNIFICANCE

Statistical significance was accomplished by using a composite score of three of the the five marksmanship characteristics, but the number of subjects that participated was simply not enough to conclude statistical significance on individual characteristics. Recognizing that the results implied that the data showed movement in one direction or another more subjects were needed in order to raise the statistical power of the results. If more time was avalible to conduct research it would be possible to take a more representative sample of marksman.

D. UNUSED DATA

Large amounts of data were gathered of all of the motion capture movements. Because of time constraints only a small portion of the data from the experiment being used for data analysis. The movements of the whole body were captured and could be analyzed for future research. The upper part of the body was studied, but if one was interested in the lower half of the body it could be researched for posture and movement analysis.

To fully understand the use of profile in the development of marksmanship training other firing positions would need further research. This thesis only analyzed the subject in the prone supported firing position. Future research should include both the kneeling and standing positions to more accurately portray shooting positions used in combat. The kneeling and standing firing positions have historically been the most difficult postures to teach because of the tendency for more body movements while firing a weapon.

Future research should include physiological changes in the body and their effects on shooting accuracy. For example, the use of a “Stress Fire” could be used to better replicate the conditions that represent in combat. The subject would fire on the EST 2000 with no stressors, add environmental stressors, and repeat the fire sequence to measure the differences in body posture. Both sequences of fire could then be compared to determine marked differences in performance. One could then attach heart rate monitors

and observe physiological changes that are more realistic with combat operations. The motion capture equipment would need to be updated and modified in order for this to become a reality.

During the experiment the subjects were not required to wear the Army's TA-50 gear. To present a more realistic depiction of combat profiles one idea for future research was to measure profiles with and without the donning of TA-50 to determine how much the TA-50 actual hinders the soldiers ability to accurately fire his weapon. The Santos virtual trainer could be used to quickly measure all of the subject's anthropometric data and align that data with differences in the subject's posture.

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APPENDIX A. – TRAINING OBSERVED IN SUPPORT OF THESIS

We first started out to see how the Army was training basic rifle marksmanship at Fort Jackson, SC. We wanted to take a look at Soldiers firing on the EST 2000 and find out what type of feedback they were getting from the simulator and observe them firing on the live M-16A2 range. Both were very helpful in determining that our research could be a valuable tool in the future. We then observed Soldiers firing on the EST 2000 and at the live M-16 A2 range that further enhanced our motivation to ensure that the EST 2000 was a valuable tool and to see the marked differences in the Drill Sergeant instructions to the Soldiers. Not necessarily good or bad, but more importantly inconsistent across the board.

We then interviewed several Soldiers from the Sniper school at Fort Benning to see if what we intended to measure using the Vikon Motion Capture System made sense. Was it essential for all expert marksmen to be proficient in 5 different rifle marksmanship tasks? Trigger pull, breathing, weapon tilt or cant, butt stock pressure, and having a consistent sight picture, placing the tip of your nose on the charging handle every time you fire your rifle. We could all agree that if you were not proficient in any one of these characteristics you could never consistently perform at an expert marksman level. We then had a sniper from Fort Benning fire using the EST 2000 to see how he would perform. He proved to be an expert marksman shooting 40 out of 40 on the simulated pop-up range. We then asked if he would perform a moving target scenario on the EST 2000 to see if his basic characteristics changed during the course of him engaging targets that were not still. He proved that he consistently stayed in the right posture what then correlates as the proper posture of an expert marksman hitting 75 out of 75 moving targets.

We knew after our Fort Benning trip that an expert marksman possesses certain characteristics, and we now had to figure out how we were going to get the Motion Capture Marker Set to link all of the joint angles in the Vikon software and then translate that data into SANTOS to show the posture of each of our subjects. We would then have to test to see if the SANTOS model was going to be precise enough to display visually

key defects in the subject's posture or not. We conducted a pilot study at the Defense Language Institute using the SANTOS protocol Marker set and had an experienced shooter fire on the EST 2000 with the Motion Capture suit on. After calibrating the cameras and putting all of the markers in place we then had the subject lay in a prone supported position and group, zero, and qualify on the EST 2000 pop-up range.

The result was that the skeleton from the marker set came out great on the computer screen, but converting the data over to create a SANTOS posture was not going to work because the new software that we installed was not compatible with the SANTOS protocol. So after figuring out that the new software was not going to be able to create our SANTOS model we had to revert back to the old 2.5 version of the Vikon software package.

The next step was conducting our experiment at the University of Iowa's Reserve Officer Training Corps (ROTC). We were a little concerned about our data collection because we were going to be using the Virtual Soldier Research Vikon Motion Capture equipment that has the 2.0 version of software. They are very experienced with the Vikon Motion Capture system and have used it for numerous other projects with very good results. They also have a different kind of camera set-up they use twelve camera's and we use five at the Naval Postgraduate School. The cameras themselves are different as they have a 75degrees coverage angle and we only have 60% coverage angle. They use 8mm marker sets where we have 14mm marker set. We went for a site recon and to meet the Virtual Soldier researchers in person for three days to actually see what they do and if our idea could become reality.

APPENDIX B. – VIRTUAL SOLDIER PARTNERSHIP

The authors teamed up with the Virtual Soldier Research team from the University of Iowa in a collaborative effort to develop a process and tool with which human-performance metrics are used to assist during marksmanship training. This project is a long term effort to develop a visual feedback tool for novice and expert marksman in an effort to improve the skills of beginners and to sustain the skills of those already trained shooters. It is the belief of those involved in this project that it is possible to develop a feedback tool that will allow immediate visual comparison of what the marksman is doing while shooting.

Motion was determined to be the best method to capture and record the posture of marksmen of varying skills. The data was used to determine the postures of marksmen of differing skill levels in an effort to compare and profile the research subjects. A baseline was established existing marksmanship doctrine to allow a determination of what expert marksmanship was according to the U.S. Army. The experimental motion-capture data was then imposed on Santos, a state-of the art virtual human. Santos which outputted not only postures that can be compared visually and subjectively, but also quantitative data including joint angles and values for human performance measures like performance, energy, joint displacement, and visual acuity. The authors were to provide motion-capture data and anthropometric data of all subjects, using VSR marker protocol and criterion. NPS would then determine anthropometric data approximately form motion-capture analysis. This partnership was consistent with our hypothesis, but because we ran out of time we were unable to render all seventeen subjects later described in the thesis.

With each trial, the subjects are instructed to stand in a T-Pose (similar to Santos front view in the attached file) for three seconds. In this posture, the subjects should look forward and extend their joints as much as they can. For example, they should extend their extremities and minimize the flexion at the elbows and the flexion at the knees. The distance between the feet should be similar to the shoulder width. After this process the

subjects can perform their tasks. The time history of the Cartesian coordinates (x, y, and z) of the markers will be used to find the joint centers and the corresponding joint angles during each task.

APPENDIX C. – WHAT IS A SIMULATIONS OFFICER

> High operational tempo (OPTEMPO), encroachment and environmental constraints require increased use of simulations and simulators for training, rehearsal and combat development (Proponent, 2007).

The United States Army established the Career Field Designation of Simulations Officer (CFD 57) from the previous functional area with the same numerical designation (FA 57). It was decided by then Army Chief of Staff General Eric Shinseki (Lunceford, 2003) that a special group of officers were needed who could use their previous operational experience and focused technical training to provide the army an enhanced training capability through the use of simulation/simulators. These officers would provide expertise in not only virtual simulations, primarily used by aviators and the mechanized forces, but they would require proficiency across all domains of simulation and army DOTMILPF (FM 3.0 Operations, 2001).

Figure 47. FA57 Emblem.

> FA 57 Officers are expert combat operations trainers responsible for enhanced combat training through simulations at the EAC, corps, division and separate brigade level. Additionally, FA 57 officers are experts at using live, virtual and constructive simulations to support training. FA 57 officers are trained in systems engineering, simulations system development and simulations operations (Proponent, 2007).

The Army has an expectation of its professional Simulation Professionals to use their collective and individual expertise to ensure that soldier are provided the best most efficient simulations and simulator to prepare for combat.

> FA57s are experts in Battle Command Integration. FA57 develop deep understanding of the Army battle Command Systems (ABCS) and through this understanding have the ability to transform information into knowledge (Proponent, 2007).

It is this experience that provides the necessary background to support research using technology to improve service member's use of both existing and future warfighting methods and technologies. It is a primary responsibility of the Simulations Officer to ensure that equipment is both developed properly and that the transition to use is made smoother for soldiers who are responsible for its employment.

APPENDIX D. – DEMOGRAPHICS AND EXPERIENCE QUESTIONNAIRE

Subject Number _____________

Age_____ Height ___ ft ___ in Weight _____lbs Arm Length_________

Rank______ Date entered military (month) _______ (year)______ ______N/A

Primary MOS______ Secondary MOS______

1. When was the last time you qualified with the M16A2 rifle?

______ Month _____ Year ________What was your score? _____N/A

2. What is your current level of weapon experience?

________ very experienced (I have shot a rifle/shotgun over 20 times)
________ some experience (I have shot a rifle/shotgun 10-20 times)
________ little experience (I have shot a rifle/shotgun less than 10 times)
________ no experience (I have never shot a rifle/shotgun)

3. Are you Right_____ or Left_____ handed?

4. Would you usually fire a rifle ____left handed or ____right handed? (Check one)

5. Would you use your ____left eye ____right eye or ____both eye to aim a weapon?

6. Do you wear glasses and/or contact lenses when you shoot? ___ Yes ___ No (Check one)

7. Do you play video games or computer games?
____Yes ____No (go to question 9)

8. How well do you play video games?
____Poor ____Below Average ____Average ____Above Average ____Excellent

9. Did you play High School or College sports? ___ Yes – (See Below)
_____No – (Got To Question 10)

    A. What Sport/Position?_______________________

    B. How Long?________________________

C. Awards Received________________________________

10. Do you have any physical limitations or prior Surgery's? _____No _____Yes (if Yes

Please explain)
____

11. Are you recovering from any cold or flu symptoms, or are you under any current medical treatment? ______Yes ______No

APPENDIX E. – SUBJECT DATA

Subject	Score	male/female	age	height (in)	weight (lbs)	Arm length (in)	experience	sports played
Subject 1	40	male	24	73	215	74.75	very exp	FB (2 years)
Subject 2	35	male	22	71	200	72.75	very exp	FB (2 years)
Subject 3	31	male	24	71	185	75	very exp	BB/T&F(4)
Subject 4	23	female	21	63	115	65	little exp	Diving/Gymnastics
Subject 5	21	male	30	65	130	64.5	little exp	none
Subject 6	37	male	35	68	130	66.6	very exp	none
Subject 7	31	male	37	67	130	66	little exp	none
Subject 8	Did not zero	male	21	71	180	76	little exp	VB/soccer (3)
Subject 9	did not zero	male	19	72	185	73.5	little exp	none
Subject 10	37	male	20	69	142	67	very exp	BB/FB/track
Subject 11	29	male	29	70	182	68	little exp	none
Subject 12	29	male	25	74	210	73.5	some exp	FB/Soccer (4)
Subject 13	Did not zero	male	22	72	170	70.25	little exp	golf (2)
Subject 14	Did not zero	male	29	70	167	69	no exp	soccer (3)
Subject 15	17	male	23	71	195	73.75	little exp	soccer/BB/BaseB
Subject 16	31	female	21	64	108	64	no exp	dance/gymnastics (15)
Subject 17	Did not zero	male	18	69	127	70.5	no exp	none

Table 22. Subject Information.

Subject	R/L handed	R/L eye domin	video games	glasses/contacts
Subject 1	right	right	excellent	no
Subject 2	right	right	excellent	yes
Subject 3	left	left	below average	no
Subject 4	right	right	no	yes
Subject 5	right	right	no	yes
Subject 6	right	right	below average	yes
Subject 7	right	right	no	yes
Subject 8	right	right	above average	no
Subject 9	right	right	above average	no
Subject 10	right	right	above average	no
Subject 11	right	right	above average	no
Subject 12	right	right	above average	no
Subject 13	right	right	average	no
Subject 14	right	right	average	no
Subject 15	right	left	above average	no
Subject 16	right	right	average	yes
Subject 17	right	right	excellent	no

Table 23. Subject Information (continued).

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APPENDIX F. – VICON MOTION CAPTURE SYSTEM

The links provided below provide information on the technical specifications of the Vicon Motion Capture System. This information is not included on this work to prevent the blotting of the work in an effort to prevent the wasteful printing of material that is available via the internet.

- This link provides the technical specifications of the T-series cameras produced by Vicon. http://www.vicon.com/_pdfs/t_cameras.pdf
- Technical specifications of the MX Giganet system used as part of the video capture system. http://www.vicon.com/products/mxgiganet.html
- Remote video sync unit. http://www.vicon.com/products/remotevideosyncunit.html
- Vicon Software Packages. http://www.vicon.com/products/software.html
- Vicon System Overview. http://www.vicon.com/products/systems.html

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